

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau



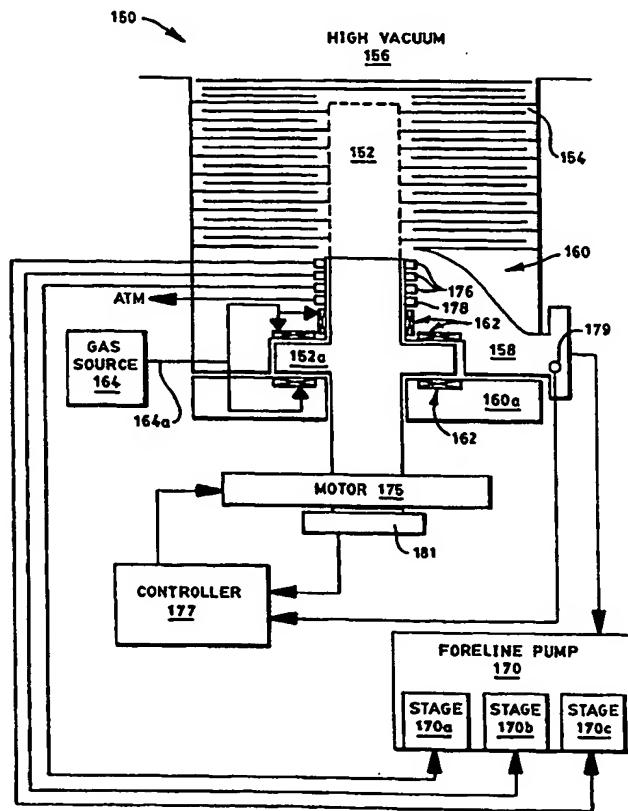
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B23Q 1/25, B65G 65/00, F04B 35/04, F16C 33/10, 33/74		A1	(11) International Publication Number: WO 99/20433 (43) International Publication Date: 29 April 1999 (29.04.99)
(21) International Application Number: PCT/US98/21417			(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
(22) International Filing Date: 9 October 1998 (09.10.98)			
(30) Priority Data: 60/062,567 21 October 1997 (21.10.97) US 09/132,726 12 August 1998 (12.08.98) US			
(71) Applicant: MULTILEVEL METALS, INC. [US/US]; 148 Sohier Road, Beverly, MA 01915 (US).		Published	<i>With international search report.</i>
(72) Inventors: POLLOCK, John, D.; 25 Kittery Avenue, Rowley, MA 01969 (US). VANDERPOT, John, W.; 29 Pearl Road, Boxford, MA 01921 (US).			
(74) Agents: VOCK, Curtis, A. et al.; Duft, Graziano & Forest, P.C., Suite 140, 1790-30th Street, Boulder, CO 80301-1018 (US).			

(54) Title: GAS BEARING TURBO PUMP AND GAS BEARING FEEDTHROUGH

(57) Abstract

A process module includes a chamber housing that can be evacuated for processing a workpiece therein. A shaft (20a) penetrating the housing permits manipulation of the workpiece. A first gas bearing sleeve (26) having a vent groove (32) couples the shaft through the housing such that the shaft is rotatable and/or translatable. A turbo pump is also provided having a gas bearing sleeve coupled to the housing to facilitate rotation of the shaft (116) within the housing. A gas conduit (136) for coupling gas to the bearings, and a vent pathway (140) are provided.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

Gas Bearing Turbo Pump and Gas Bearing Feedthrough

Background of the Invention

5 In the manufacturing of semiconductor devices, there are several processes which require the use of hostile gases at low pressures within a vacuum process module. These processes include, for example, plasma deposition, plasma etching, low pressure chemical vapor deposition and ion implantation. The nature of the gas mixtures involved in these processes renders conventional vacuum pumps and their working fluids unsuitable for use in
10 obtaining the low pressures required for the process. Depending on the process, these mixtures may be innocuous (e.g. Ar, N₂); but most are flammable, explosive, toxic, corrosive, hazardous and/or carcinogenic.

15 Historically, oil diffusion high vacuum pumps have enjoyed widespread acceptance as the pump of choice for many manufacturing processes. Such pumps are also less expensive and require smaller space as compared to Turbo pumps. By utilizing a non-hydrocarbon based oil like silicone or perfluorinated polyether, problems associated with pump oxidation, oil decomposition or explosions have been decreased. Because the diffusion pump is a throughput pump, it effectively has no pumping capacity limit, unlike the capture-style cryogenic pump
20 which requires regeneration of pumping surfaces whenever capacity is reached.

25 Over the past few years, the semiconductor industry has moved away from the use of oil diffusion pumps as part of process equipment because of contamination. The operating principle of the pump dictates that the working oil of the pump be directly exposed to the chamber that is evacuated. Oil molecules thus migrate into the process chamber, intermingle with the gases and contaminate the process. Additionally, the accidental risks are high since oil can be spread throughout the internal sectors of the equipment, creating a very difficult, costly and time-consuming cleanup task. Although the diffusion pump has clear advantages over other high-vacuum pumps, namely low cost and reliable operation, the ultra-clean
30 vacuum requirements of today's processes are demanding the use of oil-free vacuum systems.

Depending on the process, the field of choice for other types of pumps is rather limited. High-vacuum pumps can be categorized in two ways; they are either capture pumps or throughput pumps. Cryogenic, sorption, ionization, and titanium sublimation pumps fall into the former category while oil-diffusion, Turbo-molecular and Roots blower pumps fall

5 into the latter. When pumping hazardous gases, one normally prefers the throughput pump because gases are collected by the pump, compressed several orders of magnitude, expelled into the intake of yet another pump and finally exhausted into a fume collection system for treatment prior to release. Capture pumps are not desirable for pumping hazardous gases because of their inability to pump large volumes of gases before reaching full capacity.

10 Regeneration of the capture pump after reaching capacity also poses a safety threat because all of the hazardous gases initially pumped have to re-evolve from the pump's inner surfaces in order to restore the pumping capacity.

For applications such as chemical vapor deposition, which requires an evacuated chamber with hydro-carbon free high vacuums, Turbo-molecular vacuum pumps are particularly useful. Turbo pumps are basically high-speed turbines that operate on kinetic gas principles, relying on the relative motion between impacting gas molecules and moving and stationary blades. The design of the turbine stages makes it more probable that a molecule will rebound toward the outlet of the pump than toward the inlet. *See, T. A. Knecht, A new generation of turbo vacuum pumps, Research and Development, Vacuum Technology, Vol. 28, No. 3, pp. 57,59,61,62, 64-66 (March 1977) (hereinafter "Knecht").* Knecht is herein incorporated by reference as an introduction and background to turbo pumps and their operation. Turbo pumps are available through several manufacturers, including Pfeiffer and Edwards, and routinely provide pumping capability to between 10^{-6} and 10^{-9} Torr.

25

The Turbo-molecular pump has thus generally replaced the oil diffusion pump within applications where oil contamination is not allowed. Similar to the diffusion pump, a mechanical fore-pump (mechanical rotary vane or piston pump) is required in conjunction with an operating turbo pump in order to back the turbo during molecular flow conditions,

30 when the over-all pressure ratio of the multiple internal stages is maximized. *Id.* That is, when the mean free paths of the gas particles are larger than the separation between the rotating

disks, at any one stage (defined by a rotor disk and a stator disk), the collisions with the disks occur more frequently than inter-particle collisions, thus adding the blade velocity to the overall particle flow. Unlike the diffusion pump, however, the Turbo is relatively clean and does not contaminate the local vacuum environment.

5

Turbo-molecular pumps have one general weakness which has made them relatively unreliable over time - bearings. Typical pump construction involves a pair of radial or angular contact ball bearings separated axially along the shaft of a multi-stage rotor. The bearings are axially pre-loaded toward one another, shouldering their respective inner races against a feature in the shaft, and with their respective outer races pressed into a axially-retained feature located within the stationary housing that surrounds the blades. The bearings locate the rotor radially and axially within the tolerances necessary for proper blade to blade spacing between each rotor and stator stage.

15

The bearings are typically housed on the compression, or "foreline" side of the rotor/stator assembly which means that they must operate at low pressures (50-100mTorr) and must also survive the hazardous environment of the process gas. The bearings are normally lubricated in one of three ways: with low vapor pressure grease, with low vapor pressure liquid oil (both usually perfluorinated polyethers), or with a dry film lubricant. The grease lubricated bearings are generally factory prelubricated for the life of the pump and allow operation of the pump in any orientation (which is an important feature in many applications). Specifically, the grease adheres to surfaces within the bearing regardless of the direction of gravitational forces. However, as a lubricant for the bearings, and as a shield against the infiltration of dust, particulate matter and hazardous process gases, this type of lubrication system is much less effective than the liquid oil system and generally results in lower pump reliability due to premature bearing failure. The dry film lubricated bearings (i.e., Molybdenum Disulfide) have the same advantages and disadvantages as grease lubricated bearings.

25

30

Liquid lubricated systems usually require operation of the pump with the axis of the rotor shaft within 15° of vertical. This is because of the relatively low viscosity of the liquid

lubricants and the fact that gravity is generally used as the means to return the liquid lubricant to the oil sump area. These types of lubricating systems generally make the pump more expensive than the grease-lubricated counterparts; but overall performance and reliability of these pumps is somewhat better.

5

In both the oil and grease bearing lubrication scenarios described above, a small contamination source is present in the form of the lubricant itself. The lubricant poses no real contamination threat to the process while the pump is in normal steady state operation. However, during pump-down or vent-up of the process chamber, the lubricant can potentially 10 contaminate areas upstream of the bearings if valves and pumps are improperly sequenced. Additionally, both types of systems usually require that the bearings be purged with dry N₂ to help protect them from the hazards of the environment as well as to prevent lubricant from backstreaming and contaminating the process chamber. This purge gas is normally injected into the pump through a metering valve supplied with low pressure N₂ and automatically 15 opened and closed with the starting and stopping of the pump motor.

10

Certain manufacturers (e.g., Edwards) offer Turbo pumps which use magnetic levitation to support the rotor during operation. However, its disadvantages outweigh the advantages as it is extremely expensive and subject to orientation restrictions similar to those 20 of the liquid lubricated systems. Additionally, the required control electronics and magnetic power supplies make the systems very large and heavy.

20

25

30

The prior art is also familiar with the use of gas bearings with Turbo pumps. See, e.g., U.S. Patent Nos. 3,969,042; 3,832,084; and 5,451,147. However, although gas bearings provide durable and non-contaminating bearings for use with the Turbo pump, they leak atmosphere at internal stages of the pump and reduce overall pump efficiency. Specifically, gas bearings require ventilation; and the prior art air turbo pumps with gas bearings vent within the compression stage or foreline cavity of the turbo pump. This leak represents additional gas load that must be handled by the foreline pump. The effect of this incremental gas load is to raise the pressure at the fore-cavity, which in turn varies the pressure at the high

vacuum inlet of the turbo pump in direct proportion to the compression ratio (a constant). This is an undesirable outcome of venting the atmosphere directly to the forecavity.

It is, accordingly, one object of the invention to provide a turbo pump which reduces
5 or eliminates the afore-mentioned problems. Other objects of the invention include applying the pump to specific systems, such as a robot transport for wafer processing systems. Other objects of the invention are apparent within the description which follows.

Summary of the Invention

10

The following patents provide useful background information for the invention and relating to turbo pumps: U.S. Patent No. 3,832,084; U.S. Patent No. 3,969,042; U.S. Patent No. 4,929,151; U.S. Patent No. 4,893,985; U.S. Patent No. 4,764,034; U.S. Patent No. 4,734,018; U.S. Patent No. 3,753,623; U.S. Patent No. 3,947,193; U.S. Patent No. 5,451,147; 15 and U.S. Patent No. 4,180,370. Each of the afore-mentioned patents is incorporated herein by reference. A description of air bearings and their construction for rotating shafts can also be found with reference to U.S. Patent No. 4,726,689, which is also incorporated herein by reference.

20

In certain aspects, the invention utilizes gas bearings in specific applications associated with the feedthrough into a process chamber. For example, the feedthrough facilitates coupling a shaft through the wall of the chamber such as for robot handling of workpieces therein. In one aspect, gas sleeve bearings are used for a shaft feedthrough in robot and/or wafer handler in atmospheric conditions, with approximately 100psi of clean, dry gas injected to the bearings. The 25 system provides for both rotation and translation of the handler.

In another aspect, the invention utilizes gas sleeve bearing(s) in the feedthrough to a robot wafer handler in a low vacuum process chamber, where the bearing is supplied with ~100psi of clean, dry gas. Rotation and/or translation are again supported. The vacuum is maintained within 30 the chamber by grooves machined into the bearing sleeve for differential pumping.

In still another aspect, a coaxial feedthrough is provided for coupling of a shaft into a process chamber. The shaft can be used to provide counter-rotating movement of robot handling equipment within the chamber.

5 Gas sleeve bearings are highly reliable, extremely stiff, and exhibit low friction. They are also non-contaminating and moderate in cost. The invention is particularly suited for use in vacuum wafer handling systems or in conjunction with process chamber robots. In certain aspects, the bearings include differential pumping to enable use of gas (air or inert) bearings as a sealing technology for vacuum applications ($<10^{-7}$ torr). The gas consumption of these gas
10 bearings is very small owing to the tight machining tolerances, and for the same reason the requirement for differential pumping is modest (comparable to requirements for differentially pumped lip seals). By way of example, a single $\frac{1}{4}''$ - $\frac{3}{8}''$ vacuum line connected to one stage of any convenient mechanical pump is generally sufficient.

15 The invention has several advantages over the prior art, which includes sealing technologies such as magnetic coupling, lip seals, and ferrofluidic seals. These seals are usually combined with conventional mechanical bearings to provide a vacuum feedthrough capable of rotary and/or linear motion. Table I below outlines the advantages of a differentially pumped gas bearing of the invention as compared to other sealing technologies; and Table II illustrates the
20 advantages of a gas bearing over conventional mechanical bearings typically associated with the other seals.

Table I: Comparison of Gas Bearings vs. Other Sealing Technologies

Bearing	MAGNETIC COUPLED	FERROFLUIDIC	LIP SEALS	GAS BEARING FEEDTHRU
ROTARY	MECHANICAL ROTARY BEARING IN VACUUM	MECHANICAL ROTARY BEARING IN VACUUM	MECHANICAL ROTARY BEARING IN ATMOSPHERE	GAS BEARING IN ATMOSPHERE COMBINED LINEAR AND ROTARY BEARING
LINEAR	MECHANICAL LINEAR BEARING IN VACUUM	MECHANICAL LINEAR BEARING IN VACUUM	MECHANICAL LINEAR BEARING IN ATMOSPHERE	
PRECISION	POTENTIALLY LOW: MAGNETIC COUPLING SLIPPAGE / STIFFNESS	HIGH: DICTATED BY MECHANICAL BEARINGS	HIGH: DICTATED BY MECHANICAL BEARINGS	VERY HIGH: DICTATED BY GAS BEARING
FRiction	DICTATED BY MECHANICAL BEARINGS	DICTATED BY MECHANICAL BEARINGS	DICTATED BY MECHANICAL BEARINGS	VIRTUALLY NONE
LUBRICATION	REQUIRED IN VACUUM	REQUIRED IN VACUUM	REQUIRED IN ATMOSPHERE	NONE
WEAR	NORMAL BEARING WEAR	NORMAL BEARING WEAR	NORMAL BEARING WEAR	NONE
MAINTENANCE	PERIODIC LUBRICATION AND REPLACEMENT	PERIODIC LUBRICATION AND REPLACEMENT	PERIODIC LUBRICATION AND REPLACEMENT	NONE
PARTICLES CONTAMINANTS	GENERATED BY IN-VACUUM BEARINGS AND LUBRICANT	GENERATED BY IN-VACUUM BEARINGS AND LUBRICANT	NONE IN VACUUM	NONE
RELIABILITY	MODERATE	MODERATE	MODERATE	HIGH

Table 2: Advantages of Gas Bearings to Other Seals

VACUUM SEAL	MAGNETIC COUPLED	FERROFLUIDIC	LIP SEALS	GAS BEARING FEEDTHRU
ROTARY	MAGNETIC COUPLING THROUGH THIN WALL	FERROFLUIDIC SHAFT SEAL	DIFFERENTIALLY PUMPED SHAFT SEAL	DIFFERENTIALLY PUMPED NON-CONTACT SEAL
LINEAR	METAL BELLOWS	METAL BELLOWS	COMBINED LINEAR AND ROTARY SEAL	COMBINED LINEAR AND ROTARY SEAL
FRiction	NONE	LOW	MEDIUM TO HIGH	NONE
WEAR	FINITE BELLOWS LIFE; TYPICALLY 1 MILLION CYCLES RATING	FINITE BELLOWS LIFE; TYPICALLY 1 MILLION CYCLES RATING	HIGH RATE OF WEAR ON SHAFT SEALS	NONE
MAINTENANCE	PERIODIC BELLOWS REPLACEMENT	PERIODIC BELLOWS AND FERROFLUID REPLACEMENT	PERIODIC SHAFT SEALS REPLACEMENT	NONE
PARTICLES CONTAMINANTS	BELLOWS CREATES & TRAPS PARTICLES	BELLOWS CREATES & TRAPS PARTICLES FERROFLUID	PARTICLES GENERATED BY SHAFT SEALS	NONE
RELIABILITY	GOOD	GOOD	FAIR	EXCELLENT

The advantages of the differentially pumped gas bearing can be summarized as follows:

- 5 • The differentially pumped gas bearing is a single unit which provides both a high vacuum seal and a bearing capable of both rotary and linear motion.
- As a vacuum seal, the differentially pumped gas bearing is frictionless, and there is no wear, no maintenance, no particle generation, and reliability is excellent.
- As a bearing technology, a gas bearing has low friction, no lubrication requirement, no wear, no maintenance, no particle generation and excellent reliability.
- 10 • There is no contamination with a gas bearing – the bearing gas is clean, dry air (or an inert gas in oxygen-sensitive applications). The rate of transfer of bearing gas into the vacuum chamber is negligibly small, being easily handled by a small high vacuum pump without noticeable effect on the vacuum or process performance.
- The cost of gas bearings is competitive with other technologies.

The invention of one aspect includes a turbo pump with a rotating shaft and a stationary housing. Linear gas bearings – associated with a fixed gas bearing sleeve coupled to the housing – provides for low friction rotation of the shaft within the sleeve. The pump includes a pump inlet at high vacuum (i.e., low pressure), and a pump outlet for connection 5 to a foreline pump. The pump also includes a series of pressure stages, each stage including a rotor and stator (the rotors being coupled to the shaft and the stators being coupled to the housing), which provide for pumping between the pump inlet and pump outlet. A bearing inlet couples the gas bearings to a gas source (having pressurized dry gas such as N₂) through the housing and without leakage to any of the stages. Gas from the gas source pressurizes the 10 bearings to facilitate rotational motion of the shaft within the sleeve. A vent pathway couples leakage gas from between the shaft and the sleeve, through the housing (without leakage to any of the stages), and to atmosphere. The vent pathway serves to remove leakage gas that migrates along the shaft towards the pump inlet and low pressure. A vent groove, within the sleeve and adjacent the shaft, forms part of the vent path to facilitate removal of the leakage 15 gas.

The pump also provides a pump-out pathway which serves to remove residual leakage gas that migrates along the shaft from the vent groove and towards the pump inlet. The pump-out pathway couples residual leakage gas between the shaft and the sleeve, through the 20 housing (without leakage to any of the stages), and to a vacuum pump. A differential vacuum groove, within the sleeve and adjacent the shaft, and formed between the vent groove and the pump inlet, forms part of the pump-out pathway to facilitate removal of the residual leakage gas. The vent pathway and the pump-out pathway are not connected to one another pressurewise.

25

The invention also provides, in other aspects, a turbomolecular vacuum pump with rotors and stator vanes and one or more of the following features:

- Hydrostatic radial gas bearing
- Hydrostatic thrust gas bearing

- Atmosphere vent grooves, integral to the gas bearing housing and connected to outside the turbo pump area. The vent grooves allow high pressure bearing gases to escape from above the radial bearing, below the radial bearing, above the thrust bearing, below the thrust bearing, and between thrust faces.

5 • One or more vacuum pump-out grooves, integral to the gas bearing housing and connectable to an auxiliary vacuum pumping source separate from the turbo pump. The pump-out grooves allow pressure between the turbo foreline cavity and the atmosphere vent groove to be substantially reduced by differential pumping across the narrow gap of the radial gas bearing. The pump-out grooves effectively create a non-contact viscous seal which does not wear out,

10 does not produce friction or heat, does not produce particles, does not require lubrication, does not contaminate the turbo pump, and does not restrict pump attitude or orientation. This actively pumped viscous seal is compatible with corrosive media and does not significantly increase the gas load to the fore-cavity of the turbo pump.

15 • An auxiliary pumping source for the pump-out grooves as provided by different stages of a mechanical dry pump used to back the turbo foreline.

20 • A gas turbine attached to the back of the bearing housing, which directly drives the turbo pump rotor shaft. The gas turbine is driven by a supply of pressurized gas (air), which expands through the turbine, causing it to rotate, and then exhausts to atmospheric pressure.

20 The invention is next described further in connection with preferred embodiments, and it will become apparent that various additions, subtractions, and modifications can be made by those skilled in the art without departing from the scope of the invention.

Brief Description of the Drawings

25 A more complete understanding of the invention may be obtained by reference to the drawings, in which:

30 **FIG. 1** shows a process module constructed according to the invention, including a gas bearing feedthrough for coupling a shaft into the module;

FIG. 2 illustrates a coaxial feedthrough for coupling a shaft into a module, in accord with another embodiment of the invention;

5 **FIG. 3** illustrates an alternative coaxial feedthrough of the invention;

FIG. 4 shows a top view of a robot transport mechanism of the invention; and **FIG. 4A** illustrates a top view of an alternative robot transport mechanism of the invention;

10 **FIG. 5** shows a cross-sectional side view of a turbo pump constructed according to the invention; and **FIG. 5A** illustrates a similar turbo pump of the invention as driven by a pressurized gas driven turbine;

FIG. 6 illustrates differential pumping into a secondary pump in accord with one embodiment of the invention;

15 **FIG. 7** shows a cross-sectional view of a third turbo pump constructed according to the invention;

20 **FIG. 8** illustrates a processing system constructed according to the invention and including a cluster tool seal;

FIG. 8A and **8B** show front and cross-sectional views, respectively, of the cluster tool seal of **FIG. 8**;

25 **FIG. 9** illustrates a perspective view of another cluster tool seal mechanism constructed according to the invention;

FIG. 9A shows, in a perspective view, the cylindrical rotating insert for the seal of **FIG. 9**;

FIG. 9B shows, in a perspective view, a portion of the seal of **FIG. 9**, including differential pump grooves in the seal;

5 **FIG. 9C** illustrates a cross-sectional side view of the seal of **FIG. 9** in a first operating condition; and **FIG. 9D** illustrates a second cross-sectional side view of the seal in a second operating condition;

10 **FIG. 9E** illustrates an alternative embodiment of one portion of the seal of **FIG. 9**; and **FIG. 9F** shows a cross-sectional front view of the portion of **FIG. 9**;

15 **FIG. 10** schematically illustrates a gas bearing turbo pump system 400 constructed according to the invention.

Detailed Description of the Drawings

20 **FIG. 1** shows a cross-sectional view of a process module 10 constructed according to the invention. The module includes a chamber housing 12 which forms an internal chamber 14 (note that the housing 12 is shown out of scale for purposes of illustration). The chamber 14 is evacuated by operation of a vacuum pump 16 and conduit 16a, as known in the art.

25 The module 10 can be used in a variety of processes, such as ion implantation, CVD and etch processes, and semiconductor manufacturing. Such processes typically operate on a workpiece 18 such as a semiconductor wafer. The workpiece 18 is supported by a mechanical transport shown in the form of a shaft 20. By manipulation of the shaft 20, a user can position the workpiece 18 within the module 10 and manipulate the workpiece 18 in a manner desirable during processing.

30 The shaft 20 connects to a motor 22 outside of the housing 12. The motor 22 rotates the shaft 20 in a direction 24a about its center axis 20a and/or translates the shaft 20 along direction 24b. Such a motor 22 is known to those skilled in the art; and it should be

appreciated that the motor 22 can include a plurality of motors, or other devices such as air turbine drives, to provide for specific shaft motion, e.g., rotation and translation.

As a feedthrough, the shaft 20 couples through the housing 12 by an air bearing sleeve
5 26 coupled to the housing 12. The sleeve 26 includes air bearings as known in the art; and these air bearings must be pressurized with an appropriate gas. As such, the invention provides a pressurized gas source 28 that pressurizes the sleeve 26 (and in particular the air bearings within the sleeve 26) through an appropriate gas conduit 30. Representative air bearings and sleeves that can fulfill the function of sleeve 26 are made by Westwind Air Bearings, LTD.,
10 in Dorset, England, and Professional Instruments Co., in Minneapolis, Minnesota.

Though it is possible to pressurize the bearings with "air", the invention preferably utilizes inert gases such as N₂, Argon and Helium. Inert gases are preferable because there will be some minute leak of gas that reaches the volatile processes within the chamber 14; and
15 inert gases will not adversely affect these processes. By way of example, such gases will not ionize and create contaminants onto the workpiece 18.

Still, it is undesirable to "leak" the gas from the pressurized gas source 28, through
20 the sleeve 26, along the shaft 20 and into the chamber 14. Therefore, the sleeve 26 includes a vent groove 32 which vents the gas to atmosphere 34. The groove 32 connects with a vent pathway 36 which – depending on the design particulars of the module 10 – provides a low impedance pressure path for gas to escape to atmosphere 34.

Even with the groove 32, some of the gas which pressurizes the sleeve 26 will leak
25 towards the chamber 14. As such, a vacuum groove 38 differentially pumps the region 40 between the grooves 32, 38 and between the shaft 20 and the sleeve 26. A differential pressure pathway 42 connects groove 38 to a pump 44; and the vacuum applied to the pathway 42 is designed in conjunction with the entire operation of the module 10. By way of example, if the pump 16 is near capacity, then the pump 44 must operate to ensure that little if any gas leaks
30 into the chamber 14. However, if the pump 16 has excess capacity – so that it can pull

additional vacuum appropriate for the desired processes within the chamber 14 – then the pump 44 may not have to provide significant pumping.

It is precisely this sharing between pumps 16 and 44 that invoke one important feature
5 of the invention. Specifically, one preferred embodiment of the invention combines pumps 26 and 44 as a single pump system. In particular, pump 16 can for example be a turbo pump, such as described below; and pump 44 can for example be the foreline pump to the turbo pump. In FIG. 1, the combination of pump 16 with pump 44 into a single pump system is indicated by dotted line 46.

10

Those skilled in the art should appreciate that other elements and electro-mechanics can be, and typically are, included within the module 10. These elements are not shown for purposes of illustration. By way of example, for CVD processes the module 10 can include a pair of electrodes (not shown) for ionizing gas within the chamber 14 as well as gas inlets
15 and outlets (also not shown).

Pressurization of the gas bearings is typically between 80-90 psi. This pressurized gas is needed for proper bearing operation; however it is undesirable for this gas to migrate past the vent groove 32 towards the chamber 14. The goal of the vent groove 32 is to lower the
20 pressure of the gas to as low as possible. The differential pumping of the vacuum groove ensures that the pressure from the gas lowers to a sufficient level (i.e., that level at which the normal chamber pump 16 can operate to achieve proper processing pressures). As the shaft diameter increases, the vent groove size also generally increases since the vent groove operates much like a manifold. A one inch diameter shaft, for example, might typically use
25 a 1/8"-3/16" groove. The grooves and pathways should be designed so that proper pressures are attained and maintained within the chamber. By way of example, if the chamber pressure should be 10^{-7} Torr, and the maximum pumping speed of the pump 14 is 1000 liters/second, then pump 44 must ensure that the leak of gas into the chamber 16 does not exceed 10^{-4} Torr-liters/second.

30

In a cross-sectional view, FIG. 2 illustrates an alternative feedthrough 50 constructed according to the invention. For purposes of illustration, the feedthrough 50 is illustrated with only a portion of the chamber wall 52 (e.g., similar to the wall 12, FIG. 1). As above, a shaft 54 extends through the wall 52; except that in FIG. 2, the feedthrough 50 includes a pair of gas bearing sleeves 56, 58 which form the coaxial feedthrough 50. The shaft 54 and sleeves 56, 58 are generally cylindrical in shape to facilitate controlled rotation of the shaft 54 about its center axis 62 (i.e., rotation about direction 60). Sleeve 58 is fixed to the housing 52; while sleeve 56 is moveable within the sleeve 58. Specifically, sleeve 56 can rotate (about direction 60) and translate along direction 60a within sleeve 58. In addition, shaft 54 can rotate and translate within sleeve 56, providing several degrees of freedom for movement of the shaft 54.

Each gas bearing sleeve includes gas bearings which are pressurized from one or more external gas sources 64. As above, gas from the gas source(s) 64 can be air; but preferably is an inert gas. Gas conduits 66 provide a pathway through which the bearings are pressurized. As illustrated, for example, gas source 64a pressurizes air bearings within sleeve 58 through pathway 66a; and gas source 64b pressurizes air bearings within the sleeve 56 through pathway 66b.

As in FIG. 1, each gas bearing sleeve includes a vent groove 72 and a vacuum groove 74 (specifically, sleeve 58 has vent groove 72a and vacuum groove 74a; and sleeve 56 has vent groove 72b and vacuum groove 74b). The vent grooves 72 couple to atmosphere ("ATM") through a vent pathway 76 (pathway 76a for sleeve 56, and pathway 76b for sleeve 56); and vacuum grooves 74 couple to vacuum pumps 78 through the pump-out pathway 80 (pathway 80a couples to pump 78a for sleeve 58, and pathway 80b couples to pump 78b for sleeve 56). The pathways 76, 80 are designed to provide performance (such as described in connection with FIG. 1) even through the various movements of shaft 54 and sleeve 56.

Note that rotation of the shaft about direction 60 can occur simultaneously with counter-rotation (opposite to direction 60) of the sleeve 56, providing for coaxial rotation which is advantageous in driving robot mechanisms, as described in more detail below. The rotation of the shaft 54 and counter-rotation of the sleeve 56 can readily occur at the control

rates desired by robot transport mechanisms, e.g., 35-50mm per stroke and $\frac{1}{2}$ revolution per second.

5 **FIG. 2** also illustratively shows three motors 70: motor 70a provides for rotation and positioning of shaft 54 with respect to sleeve 56; motor 70b provides for rotation and positioning of the sleeve 56 with respect to the chamber wall 52; and motor 70c provides for translation of sleeve 56 with respect to the chamber wall 52. By way of comparison, motors 70b, 70c provide for rotation and translation of sleeve 56 much the way motor 22 does for the shaft 20 of **FIG. 1**.

10

The motors 70 are known in the art and can be configured several ways as a matter of design choice. Typical manufacturers of such motors include NSK, Yaskawa and PMI.

15 Those skilled in the art should appreciate that the motor 70a can also provide for translation of the shaft 54 within the sleeve 56, similar to the shaft movements described in connection with **FIG. 1**. However, the shaft can also be made to include a disk which mates with the sleeve such that translation of the shaft only occurs in conjunction with movement of the sleeve, such as shown in **FIG. 3**.

20

FIG. 3 illustrates an alternative feedthrough 90 constructed according to the invention. The feedthrough 90 is similar to the feedthrough 50 of **FIG. 2**; except that the shaft 92 includes a thrust bearing 92a that meshes within a mating chamber 94 within the sleeve 56' (like numbers indicate substantially similar items between **FIGS. 2 and 3**). The chamber 94 is formed by an extension of the sleeve 56' which includes additional gas bearings for movement of the thrust bearing 92a within the chamber 94. As such, gas source 64b additionally supplies gas to the bearings at chamber 94 by way of the gas conduit 66b'. Accordingly, translational movement of the shaft 92 occurs only with simultaneously translational motion of the sleeve 56' by operation of motor 70c.

25

As above, note that rotation of the shaft 92 about direction 60 can occur simultaneously with counter-rotation (opposite to direction 60) of the sleeve 56', providing

for coaxial rotation which is advantageous in driving robot mechanisms, as illustrated in **FIG. 4**. **FIG. 4** illustrates a robot mechanism 100 constructed according to the invention. The mechanism 100 includes four arms 102a-d. Arms 102a and 102b couple at joint 104, and arms 102c and 103d couple at joint 106, such that rotation 108 of arm 102a with counter rotation 110 of arm 102c causes translational movement 112 of workpiece holder 114. The mechanism 100 is driven by a coaxial feedthrough and shaft such as described in **FIGS. 2** and **3**. In particular, through appropriate linkages, known in the art, the shaft 54 (**FIG. 2**) or 92 (**FIG. 3**) couples to one rotation point 116; while the sleeve 56 or 56' of **FIGS. 2** and **3**, respectively, couples to rotation point 118. When the shaft and sleeve are counter-rotated, therefore, translational movement 112 is achieved. Further, by translation of the shaft along direction 60a, the holder 114 raises and lowers accordingly. In sum, therefore, selective robotic movement is achieved for the holder 114 by rotation and/or translation of the shaft and coaxial feedthrough of the invention. Those skilled in the art should appreciate that rotations 108, 110 can also be implemented through a pair of non-coaxial shaft bearing systems, each system having shaft and gas-bearing feedthrough such as illustrated in **FIG. 1**, for example.

FIG. 4A shows, in a top view, an alternative robot mechanism 100' which is similar to mechanism 100 of **FIG. 4** except that counter-rotation of arms 102a' and 102c' in directions 108' and 110', respectively, occurs along a single co-aligned axis defined by rotation point 116'. The robot mechanism 100' can be driven by a shaft and dual gas-bearing feedthrough such as illustrated in **FIG. 2**, for example.

FIG. 5 shows a cross-sectional side view of Turbo Pump 110 constructed according to the invention. The pump 110 operates to evacuate air from the environment connected to the inlet 112 and to couple the air to the foreline cavity 114 which connects to a vacuum pump 116. A motor 117 rotates the shaft 116 within a housing 118; and vertical motion 120 of the shaft 116 is bounded by the shaft's thrust collar 116a that is captured between the thrust plate 118a and the housing 118. Pumping is created within the several compression stages 122 as the shaft 116 rotates, each stage having a rotor 122a and stator 122b providing a compression ratio. The overall pump compression ratio is the product of the individual stage ratios.

FIG. 5A illustrates a Turbo Pump 110' which is similar to the pump 110 of **FIG. 5** except that rotation of the shaft 116 is provided by a pressurized gas driven turbine 119. Such turbines are known in the art; and an exemplary system to drive the turbine 119 is shown in **FIG. 9.**

5

The description of **FIGs. 1-3** includes differential pumping of gas bearings relative to a shaft. Similar to this, **FIG. 5** and **FIG. 5A** include a rotating shaft 116 that rotates within the housing 118 by operation of gas bearings arranged along position 132. Even the thrust collar 116a rotates relative to the thrust plate 118a via gas bearings at position 134. Accordingly, a 10 gas source 132 pressurizes these positions 132, 134 through a pump pathway 136 which extends through the housing 118 and/or thrust plate 118a. As above, a vent groove 138 vents leakage gas (i.e., that gas from the source 132 which pressurizes the bearings at locations 132, 134 and which migrates towards the inlet 112 along the shaft 116), through vent pathway 140, to atmosphere ("ATM") so as to reduce leakage into the high vacuum inlet area 112. Also as 15 above, residual leakage gas (i.e., that gas which is not vented to ATM through vent groove 138) is captured by the vacuum groove 142, connected to vacuum source 116a through pump-out pathway 144.

20 The design of the prior art gas bearing turbo pumps vent the gas bearings such that a leak is formed into the compression stages, thereby adding gas load to the forepump area. The prior art thus vents air bearings into the foreline, an undesirable result. The design of **FIGs. 5** and **5A** overcome this problem of the prior art.

25 **FIG. 6** illustrates a multi-stage differentially evacuated turbo pump system 150 constructed according to the invention. As above, the pump 150 has a shaft 152 which rotates a series of compression stages 154 to create a vacuum differential between high vacuum 156 and the foreline 158. The shaft 152 has a thrust collar 152a bounded between the pump housing 160 and thrust plate 160a. A series of gas bearings 162 are fed by a gas source 164 (i.e., pumping inert gas through pathway 164a) to high quality bearing control of the shaft 30 rotation. A foreline pump 170 connects to the foreline 158 to provide the secondary vacuum to the foreline 158. Those skilled in the art are familiar with foreline pumps; and particular

that such pumps 170 can be mechanical vacuum pumps with one or more vacuum stages 170a-170c.

The pump 150 of **FIG. 6** takes advantage of the several stages 170a-c within the pump 170 to provide differential pumping of leakage gas generated from the bearings 162. Stage 172a, for example, provides a first pumping stage to stem the migration of leakage gas towards the inlet 156; while stages 172b and 172c provide second and third stages, respectively, of pumping of the leakage gas, with stage 172c providing the greatest differential pumping capacity. Those skilled in the art should appreciate that more or fewer stages 172 can be connected to capture leakage gas. Each stage 172 connects to an associated vacuum groove 176 to operate as described above. Though not required, a vent groove 178 can also be used to vent leakage gas to ATM through a pathway 178a.

Pumps 110 and 150 provide several advantages over the art. Specifically, very fast pump rotations of tens of thousands of RPMs are achieved with an inert gas purge and differential pumping of leakage gas. In **FIG. 6**, an added advantage is obtained through coupling foreline mechanical stages to differential vacuum grooves in the gas bearing sleeve. Because of the inert purge, the bearing of the invention inhibits corrosion by excluding corrosive gases from the bearing area. The gas bearings provide increased reliability and stiffness, as compared to classical bearings, and they do not wear. Further, the turbo pump of the invention is orientation insensitive, unlike prior art oil lube or maglev turbo pumps, providing additional degrees of freedom in the use of the pump. The turbo pump of the invention is also a dry pump system, not requiring lubrication or hydrocarbons. Finally, these pumps are less expensive than maglev pumps, for example, even though they too do not require lubrication.

Those skilled in the art should appreciate from the description herein (and in particular from the description of **FIGs. 5A** and **9**) that the motor 175 and controller 177 can be substituted with a pressurized gas turbine and a flow controller device in accord with other 30 embodiments of the invention.

In a cross-sectional view, FIG. 7 illustrates another embodiment of a turbo pump 200 constructed according to the invention. As above, a pump inlet 202 couples through the pump's compression stages 204 and to the pump outlet 206 (which connects to a forepump).

The shaft 208 is rotated by a motor or gas turbine drive 210 as facilitated by gas bearings 212 (although not shown, a gas source provides air or gas to the bearings 212, as above). The gas bearings 212 follow the shaft 208; but the shaft 208 and rotor rotation are defined by known mechanical bearings 216 (unlike above, where the air bearings define the rotor and shaft rotation). In FIG. 7, the air bearings 212 are mounted with a separate housing 218 which is rigidly attached (via mounts 220) to the stationary housing 222 associated with the compression stages and foreline cavity 224. The housing 218 includes a vent groove 224 that vents "V" the bearings 212 to atmosphere; and a pump groove 226 that provides for pumping "P" the bearings 212 to remove leakage gas generated thereby. In this manner, the bearings 212 do not affect the compression of the compression stages 204; and they further do not leak to the foreline cavity 224.

15

One other advantage in the turbo pumps described above is that such pumps are easier to control than prior art turbo pumps. Prior art turbo pumps using mechanical bearings require the drive electronics to avoid driving at the resonant frequencies of the pump. Such controllers are expensive, costing upwards of 30% of the entire system; and they can be unreliable. With the invention, a resonant sensing motor controller may not be required. In FIG. 6, for example, motor 175 is shown illustratively as the mechanism which drives the shaft 152. A controller 177 couples to the motor 175 to control its operation. The controller 177 also couples to a mass flow rate sensor 179 in the foreline 158 to sense pressure and flow rate, and to a speed sensor 181 which senses shaft rotation rate. The information from the sensors 17, 181 is sufficient to drive the motor 175 and hence the shaft 152 to ensure proper operation.

FIG. 8 illustrates a top view of a processing system 300 constructed according to the invention and used, for example, in processing semiconductor wafers. A robot and wafer handling section 302 interfaces to three separate process modules 304a-304c by way of a

cluster tool seal 306. Each module 304 can provide separate processing such as in CVD. The section 302 can for example include a robot described in connection with **FIG. 4**.

The invention lies in the cluster tool seal 306, shown in a front view (i.e., so as to view face 309, **FIG. 8**, of the seal 306). The section 302 includes robotic mechanisms (not shown, though known in the art) to manipulate the position of the seals 306 to position and alternatively remove the seals from the modules 304. The seals 306 are used to seal the respective process module 306 from the section 302 to prevent contamination of the section 302 by the process chemistries of the modules 306. The section 302 can also be held at atmosphere, and a module 304 can be held at vacuum with the seal 306 in place; and thus the seal 306 must seal the section 302 from the module 304 pressurewise.

In the prior art, cluster tool seals included rubber o-rings which provided the pressure seal when positioned at the module interface. These o-rings were subject to failure in view of the high temperature operation in the system and of the corrosive environments typical with semiconductor processing, for example. They further provided a source of contamination in that the associated elastomer fails.

The seals 306 of **FIG. 8** do not include o-rings. In **FIG. 8A**, one seal 306 is shown in a frontal view; and in **FIG. 8B**, one seal 306 is shown in a cross-sectional view coupled to a process module interface 320. Each module 304 has an access opening 322 which permits inserting and alternatively removing wafers between the section 302 and the module 304. The seal 306 thus seals the opening 322 pressurewise to prevent fluid coupling between the module 304 and the section 302.

25

The seal 306 is provided by one or more grooves 308 within the seal, with each groove 308 coupled to a vacuum source 312. The vacuum applied to the grooves 308 causes the seal 306 to adhere to the interface 320 such that little or no leak occurs through the seal 306, between the section 302 and module 304. The grooves 308 can be pumped differentially, such 30 as discussed above in connection with **FIG. 6**, and even within the common pump 312

(though those skilled in the art should appreciate that additional pumps 312 can be used to provide the differential pumping).

Though not required, the seal 306 can additionally have a vent groove 310 which vents 5 between the grooves 308. For example, the vent 310 can vent to atmosphere (as illustrated in FIG. 8B) when the section 302 is at atmosphere.

The seal 306 thus provides advantages over the art. First, it has no o-rings and thus is more robust with little likelihood of failure. Further, the differential pumping of the grooves 10 308 provide for large vacuum differentials between the module and the section 304. The seal 306 can be made of completely durable material such as aluminum.

FIG. 9 shows an alternative cluster seal system 330, which interfaces (for example) between two process chambers and which passes workpieces (e.g., wafers) between chambers. 15 As above, the chambers can have very different pressures and chemistries and the seal 330 operates to preserve the integrity of the chamber environments, as well as operationally provide for passage of the workpieces therebetween. For purposes of illustration, seal 330 is shown as a single unit when in fact the seal is integrated with the process chambers. Seal 330 can also be made integrally with the process chambers, if desired.

20

The seal 330 has a housing 331 (e.g., made from Aluminum) that forms a slot 332; the slot 332 being large enough to pass workpieces therethrough. A rotating member 334 (i.e., a rotatable valve cylinder), shown as an independent unit in FIG. 9A, fits within the seal 330 such that the member 334 can rotate and interact with the slot 332 (shown operationally in 25 FIGs. 9C, 9D). The member 334 thus forms its own mating slot 332a which – together with the slot 332 – forms a passageway through the seal 330 when the member is rotated to the correct position (as shown in FIG. 9D).

Similar to the systems and mechanisms discussed above, seal 330 is preferably 30 differentially pumped at the interface between the member 334 and the housing 331 to provide integrity between adjacent chamber environments and to prevent leakage between chambers.

The differential pumping is accomplished through pump ports 335 which couple to a groove 338 at the interface between the member 334 and the housing 331 (as shown in more detail in **FIG. 9B**, which illustrates a lower portion 331a of the housing 331 of **FIG. 9**). The member 334 thus rotates within the housing 331 as facilitated by bearings 336 (either mechanical 5 bearings or preferably gas bearings, discussed above), **FIG. 9B**.

Those skilled in the art should appreciate that **FIG. 9-9F** are illustrative and that other components – e.g., pump sources and drive mechanisms – should be coupled to the cluster seal to provide correct operation. The description above provides suitable examples of drive 10 mechanisms and pump sources which can be used in this regard.

FIG. 9C illustrates a first operational view of the seal 330 in a CLOSED condition, where chamber environments 340, 342 on opposite sides of the seal 330 are sealed from one another; and **FIG. 9D** shows an OPEN condition, ninety degrees out of phase with the OPEN 15 condition, whereby workpieces can pass through the co-aligned slot 332, 332a providing a passageway between environments 340 and 342. There is minimal clearance 344 between the member 334 and the housing 331, which assists in differentially pumping (as described herein) the seal 330 via the pump out pathway 346.

FIG. 9E shows an alternative cluster seal portion 350 constructed according to the invention in a form similar to the portion of **FIG. 9B**. In **FIG. 9E**, the housing 331' includes a bearing area 352 to facilitate rotation of the rotatable valve cylinder 334', **FIG. 9F**, within the bore 353. Preferably, the bearing area 352 includes gas bearings such as discussed above which are pressurized and then differentially pumped by vacuum grooves 354 and/or 25 differentially pumped longitudinal groove 356 (e.g., similar to groove 338, **FIG. 9B**). A vacuum pump (not shown) connects to the groove 356 via a pump pathway, e.g., pathway 360.

FIGs. 9-9F thus provide alternative embodiments to sealing one chamber from another, while still providing needed and compact functionality for passing wafers between 30 chambers by rotating the cylindrical valve about axis 370; as shown by arrow 372, **FIG. 9F**.

In accord with those systems of the invention that utilize a gas turbine drive, a pressure and flow rate controller (i.e., a mass flow controller) is used in feedback with the turbo shaft rotation speed to provide complete control over the pump, such as shown in FIG. 10, illustrating a gas bearing turbopump system 400 constructed according to the invention. In 5 FIG. 10, compressed air is injected through the inlet 402 and coupled to a bearing air shutoff 404. The shutoff 404 is typically open for air to pressurize the gas bearings 406 (for purposes of illustration, the bearings 406 are shown isolated from the turbo pump (not shown in FIG. 10)). Gas that passes the shutoff 404 is stored and buffered within the ballast tank 408, which stores pressurized gas in case of a failure of the facility's main supply that pressurizes inlet 10 402: when such a failure occurs, the system 400 senses the failure and shuts off the valve 404. A refrigerator air dryer (or membrane filter) 410 is powered by facility voltage 412 to provide dry clean gas to the bas bearings 406.

In the other path from the inlet 402, which pressurizes and drives the air turbine 414, 15 pressurized gas couples to an air pressure switch 416 which senses a minimum level of air pressure needed to drive the gas turbine 414. The main controller 418 controls the turbine drive 414 by sensing, for example, frequency of vibration (and hence rotational speed) and temperature within the turbine drive 414 (i.e., via accelerometer and thermocouple sensors 420a, 420b within the turbine 414). The controller 418 uses the sensed information to control 20 the turbine air bypass 422 and turbine air control 424, which is open when the turbo drive 414 is in motion. The valve 424 can be closed (thereby shutting down the drive 414) by the controller 418 if speed or temperature sensing reflects an unsafe condition, for example. A power supply 426 powers the controller 418 via connected facility voltage 412.

25 A turbine air filter 430 filters gas before injection to the drive 414. In operation, a turbine muffler 432 efficiently disposes of exhaust from the drive 414 to an outlet 434.

There are several advantages of utilizing gas turbines to drive turbo pumps of the 30 invention. First, motors and control electronics are more expensive than air turbines and air flow control devices. Secondly, control electronics for motors are larger and heavier than air flow control devices. Third, motor controllers generate vibratory forces at varying frequencies

which may excite the natural frequencies of the bearings; and gas turbines do not generate these input vibrations. Fourth, a common gas source can feed both the gas bearings (providing other advantages as discussed in detail above) and the turbine drive, as shown in **FIG. 10**. Regardless of the drive type (e.g., motor or gas turbine), a vibration sensor (e.g., accelerometer 5 420a, **FIG. 10**) located on the pump can be used to sense pump speed (RPMs) as well as pump vibration. This pump speed feedback can then be fed into the control electronics to control pump speed via the associated drive (e.g., a motor or gas turbine). This feedback further adds safety by monitoring pump and bearing performance to avoid potentially damaging failures.

10

The invention thus attains the objects set forth above, among those apparent from the preceding description. Since certain changes may be made in the above methods and systems without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawing be interpreted as illustrative and not 15 in a limiting sense. It is also to be understood that the following claims are to cover all generic and specific features of the invention described herein, and all statements of the scope of the invention which, as a matter of language, might be said to fall there between.

Having described the invention, what is claimed is:

20

1. A process module of the type which includes a chamber housing that is evacuated for processing a workpiece therein, the housing forming a chamber that holds a vacuum, comprising:

5 a shaft, penetrating the housing, for manipulating the workpiece within the chamber by movement of the shaft,

a first gas bearing sleeve for coupling the shaft through the housing, the shaft being rotatable within the first sleeve through operation of gas bearings within the first sleeve;

10 a first vent groove within the first sleeve and adjacent to the shaft for venting leakage gas which migrates from the bearings of the first sleeve, along the shaft and toward the chamber; and

15 a first vacuum groove within the first sleeve and adjacent to the shaft for pumping leakage gas which migrates from the first vent groove of the first sleeve, along the shaft and to the chamber.

2. A module according to claim 1, further comprising a gas source for providing gas to the gas bearings of the first sleeve.

20 3. A module according to claim 1, wherein the gas comprises an inert gas.

4. A module according to claim 1, further comprising a first motor coupled to the shaft for rotating the shaft relative to the first sleeve.

25 5. A module according to claim 1, further comprising a second motor coupled to the shaft for translating the shaft relative to the first sleeve.

30 6. A module according to claim 1, further comprising a first pump connected to the first vacuum groove for evacuating leakage gas through the vacuum groove.

7. A module according to claim 1, wherein the module comprises means for venting the first vent groove to atmosphere.
8. A module according to claim 1, further comprising a second gas bearing sleeve
5 constructed and arranged coaxially about the first sleeve, the second sleeve being rigidly fixed to the housing, the first sleeve being rotatable within the second sleeve through operation of gas bearings within the second sleeve, the second sleeve having (a) a second vent groove within the second sleeve and adjacent to the first sleeve for venting leakage gas which migrates from the bearings of the second sleeve, along the first sleeve and toward the chamber and (b) a second
10 vacuum groove within the second sleeve and adjacent the first sleeve for pumping leakage gas which migrates from the second vent groove of the second sleeve, along the first sleeve and to the chamber.
9. A module according to claim 8, further comprising a third motor for rotating the first
15 sleeve relative to the second sleeve.
10. A module according to claim 8, further comprising a fourth motor for translating the first sleeve relative to the second sleeve.
- 20 11. A module according to claim 8, further comprising a second gas source for providing a second gas to the gas bearings of the second sleeve.
12. A module according to claim 11, wherein the second gas comprises an inert gas.
- 25 13. A module according to claim 8, further comprising a gas source for providing gas to the gas bearings of the first and second sleeves, the gas comprising an inert gas.
14. A module according to claim 8, further comprising a second pump connected to the second vacuum groove for evacuating leakage gas of the second sleeve through the second
30 vacuum groove

15. A module according to claim 8, wherein the module comprises means for venting the second vent groove to atmosphere.

16. A module according to claim 8, wherein the shaft comprises a thrust collar, and further
5 comprising a thrust plate for restricting axial translation of the shaft with respect to the first sleeve.

17. A module according to claim 8, further comprising a robot within the chamber and coupled through linkages to the shaft and first sleeve, the workpiece being supported by the
10 robot, the robot being responsive to counter rotations of the first sleeve with respect to the shaft such that the workpiece experiences a first translational movement within the chamber.

18. A module according to claim 8, further comprising means for translating the first sleeve and the shaft relative to the second sleeve, the robot being responsive to the translating of the first
15 sleeve and the shaft wherein the workpiece experiences a second translational movement within the chamber, the second translational movement being substantially perpendicular to the first translational movement.

19. A turbo pump system, comprising:

20

a shaft and a stationary housing;

a gas bearing sleeve coupled to the housing to facilitate rotation of the shaft within the housing, the sleeve having one or more gas bearings;

25

a pump inlet for coupling the pump to a region of low pressure;

a foreline;

30 a series of compression stages, each stage having a rotor coupled to the shaft and stator coupled to the housing, which provide for pumping between the inlet and the foreline during rotation of

the shaft;

a gas conduit for coupling gas to the bearings without leakage to the stages;

5 a vent pathway for venting leakage gas from between the shaft and the sleeve, through the housing, and to atmosphere, the vent pathway removing leakage gas that migrates along the shaft towards the inlet and low pressure;

10 a vacuum pathway for removing leakage gas that migrates along the shaft from the vent pathway and towards the inlet; and

means for coupling a vacuum pump to the vent pathway.

20. A turbo pump system according to claim 19, wherein the vent pathway comprises a vent
15 groove within the sleeve and adjacent to the shaft.

21. A turbo pump system according to claim 19, wherein the vacuum pathway comprises a pump out groove within the sleeve and adjacent to the shaft.

20 22. A turbo pump system according to claim 19, further comprising a vacuum pump for
evacuating leakage gas through the vacuum pathway.

23. A turbo pump system according to claim 19, further comprising a gas source for
providing gas for the bearings.

25

24. A turbo pump system according to claim 23, wherein the gas comprises inert gas.

25. A turbo pump system according to claim 19, further comprising a motor for rotating the
shaft selectively.

30

26. A turbo pump system according to claim 19, further comprising a foreline pump

connected to the foreline, to provide secondary pumping of the pump system.

27. A turbo pump system of claim 26, wherein the foreline pump comprises at least one pump stage, and further comprising means for coupling the vacuum pathway to the pump stage to

5 evacuate leakage gas from vacuum pathway.

28. A turbo pump system of claim 19, further comprising one or more additional vacuum pathways for removing residual leakage gas which migrates from the vacuum pathway along the shaft and to the inlet, and further comprising a foreline pump having a plurality of pump stages,

10 each stage coupled to a vacuum pathway to provide differential pumping of leakage gas.

29. A turbo pump system according to claim 19, further comprising a gas turbine drive for rotating the shaft selectively.

15 30. A cluster tool seal system for sealing a process module from a robot handling section, the module forming an aperture for passing workpieces between the module and the section, comprising:

20 a plate having a first surface larger than the aperture and which interfaces against the module to cover the aperture; and

a first groove in the first surface, the first groove being circumferentially disposed about the first surface and about a region on the first surface corresponding to the aperture, wherein a vacuum applied to the first groove causes the plate to seal against the module to prevent leakage between the module and the section.

25 31. A system according to claim 30, further comprising a vacuum source coupled to the first groove for drawing a vacuum at the first groove.

30 32. A system according to claim 30, wherein the plate further comprises a second groove in the first surface, the second groove being circumferentially disposed about the first groove,

wherein a differential vacuum applied to the second groove creates a differential seal against the module to prevent leakage between the module and the section.

5 33. A system according to claim 32, further comprising a second vacuum source coupled to
the second groove for drawing a vacuum at the first groove.

10 34. A system according to claim 30, wherein the plate further comprises a vent groove in the
first surface, the vent groove being circumferentially disposed between the first groove and the
second groove, wherein the vent groove vents to atmosphere within the section.

15 35. An inter-chamber seal between process chambers, comprising:

a housing coupled with the chambers and forming a bore and a first slot between the chambers;

20 a rotatable cylindrical valve, constructed and arranged to fit within the bore and forming a second
slot, the first and second slots forming a passageway between the chambers when the valve is
rotated to an OPEN condition, and sealing one chamber from the other when the valve is in a
CLOSED condition, the seal sealing one process chamber from another in the CLOSED
condition and alternatively permitting passage of workpieces through the seal in the OPEN
condition; and

25 means for differentially pumping between the valve and the housing to substantially restrict
leakage between chambers.

30 36. A seal according to claim 35, further comprising gas bearings constructed and arranged
with the housing at the interface to facilitate rotation and sealing of the valve within the bore.

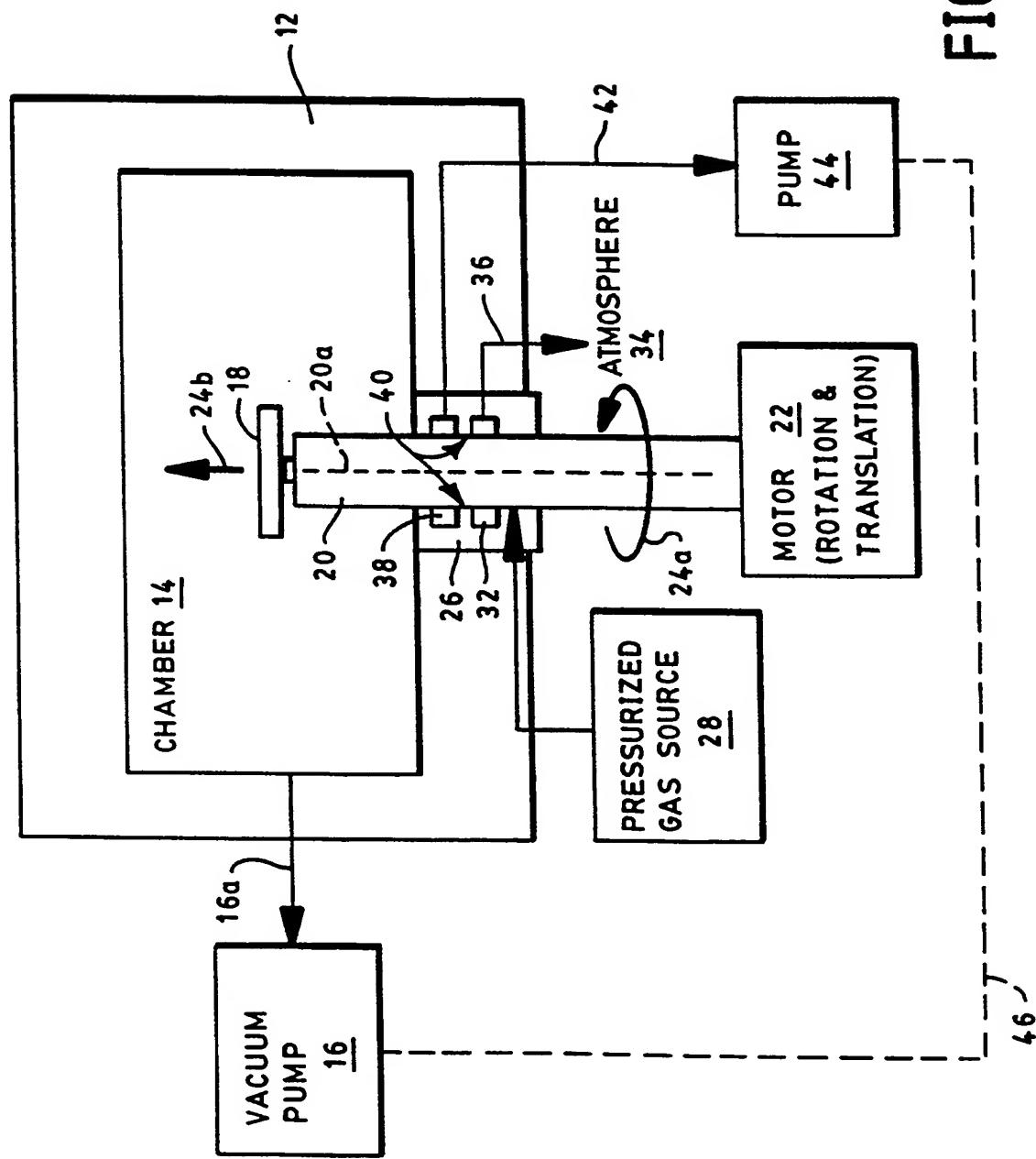
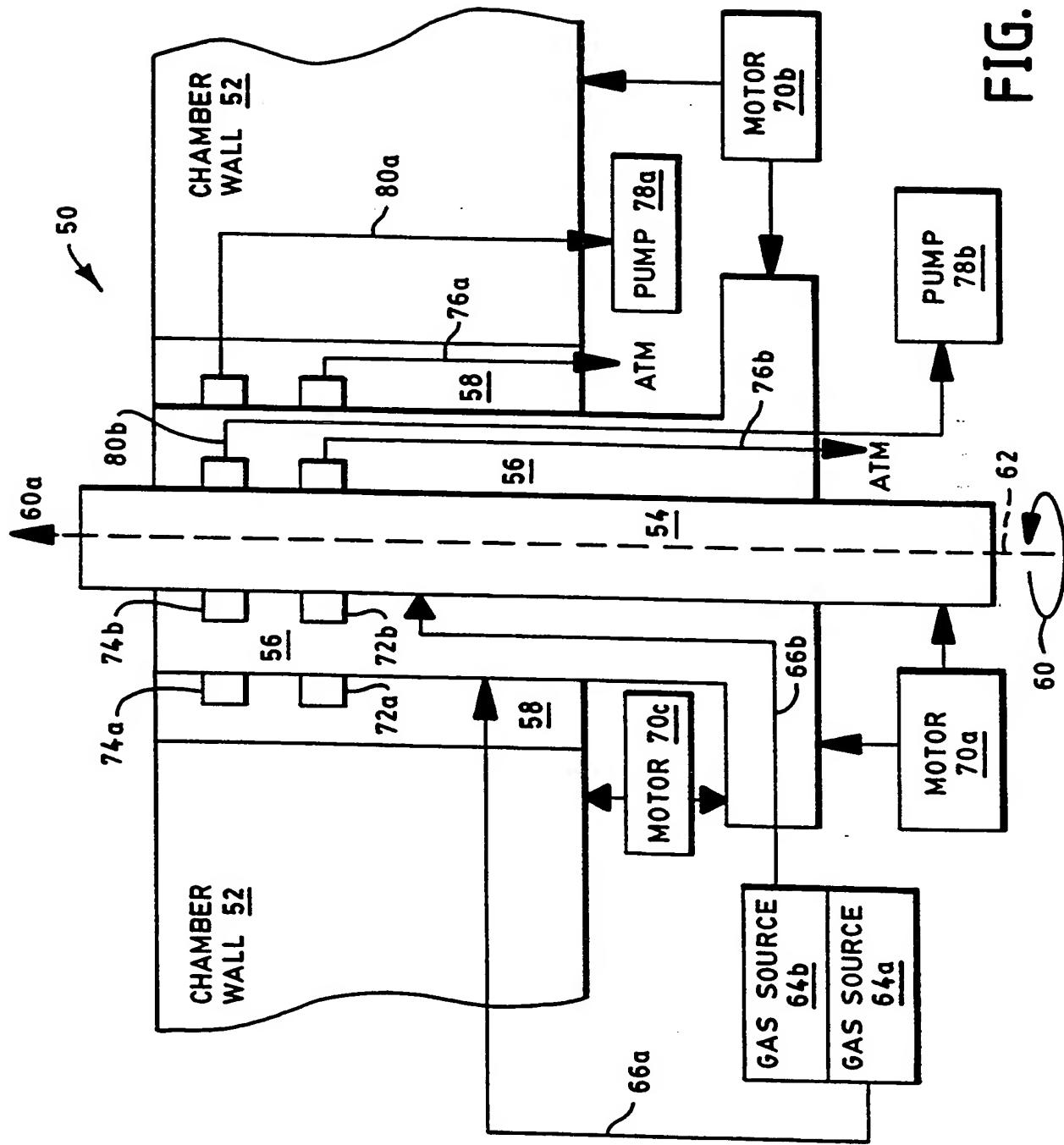
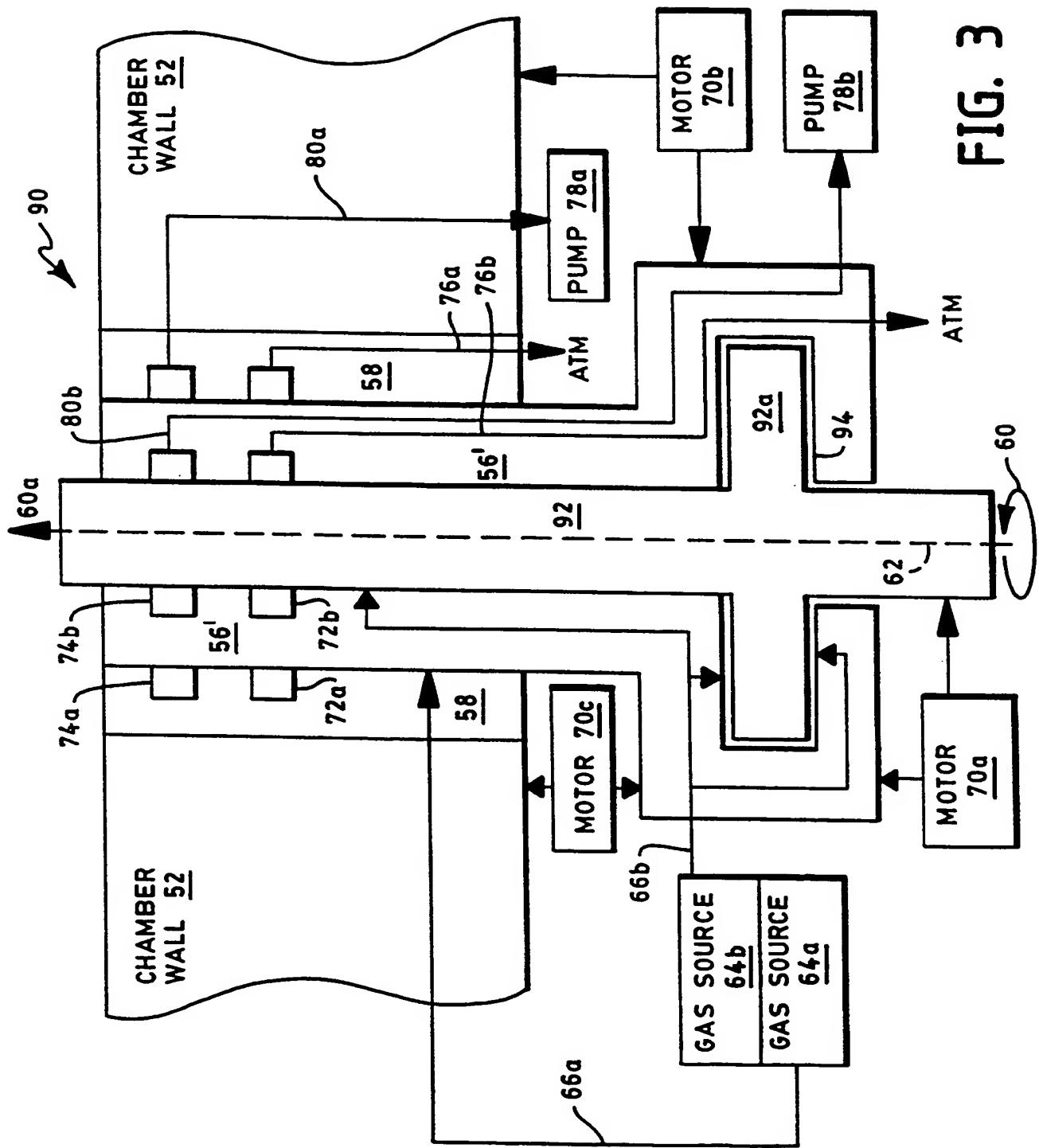
ζ^{10} 

FIG. 1

FIG. 2



3/13

**FIG. 3**

4/13

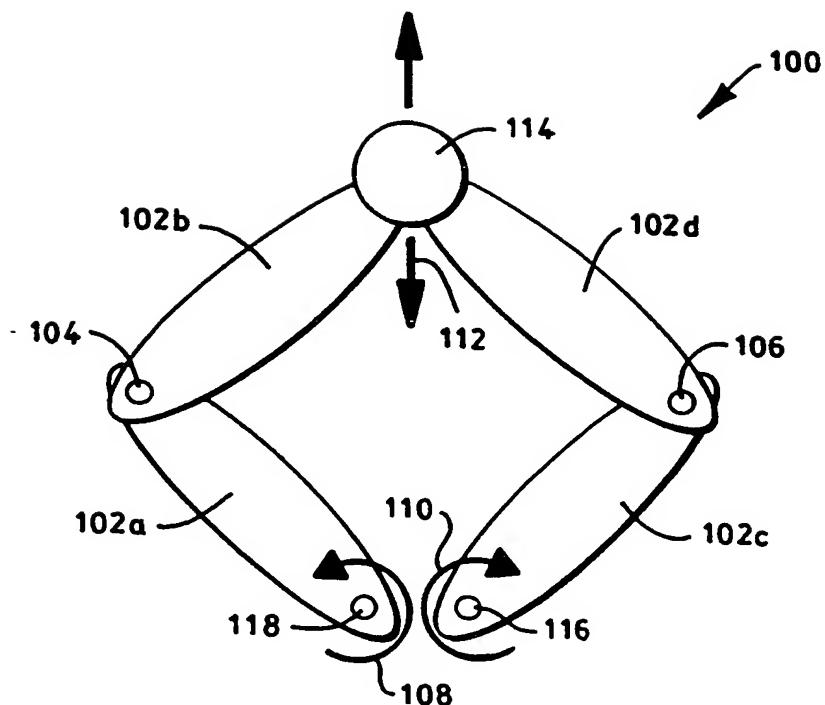


FIG. 4

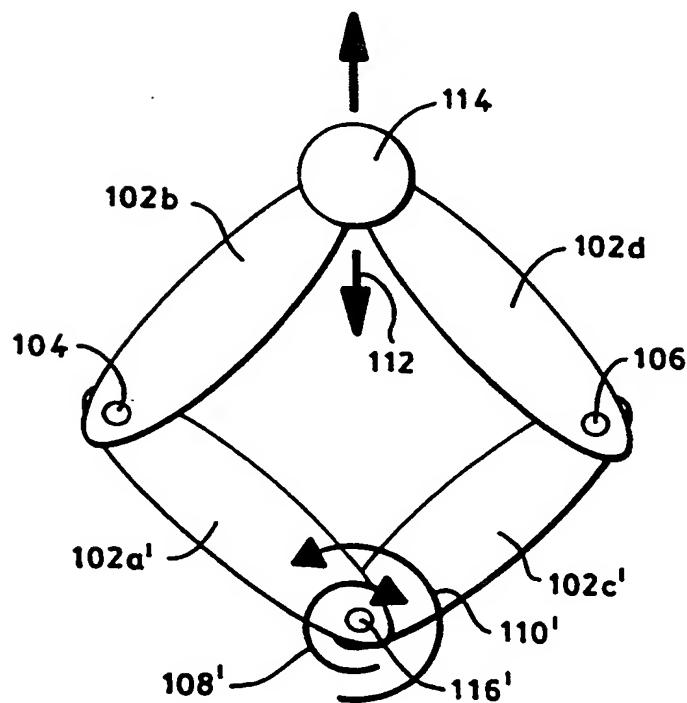


FIG. 4A

5/13

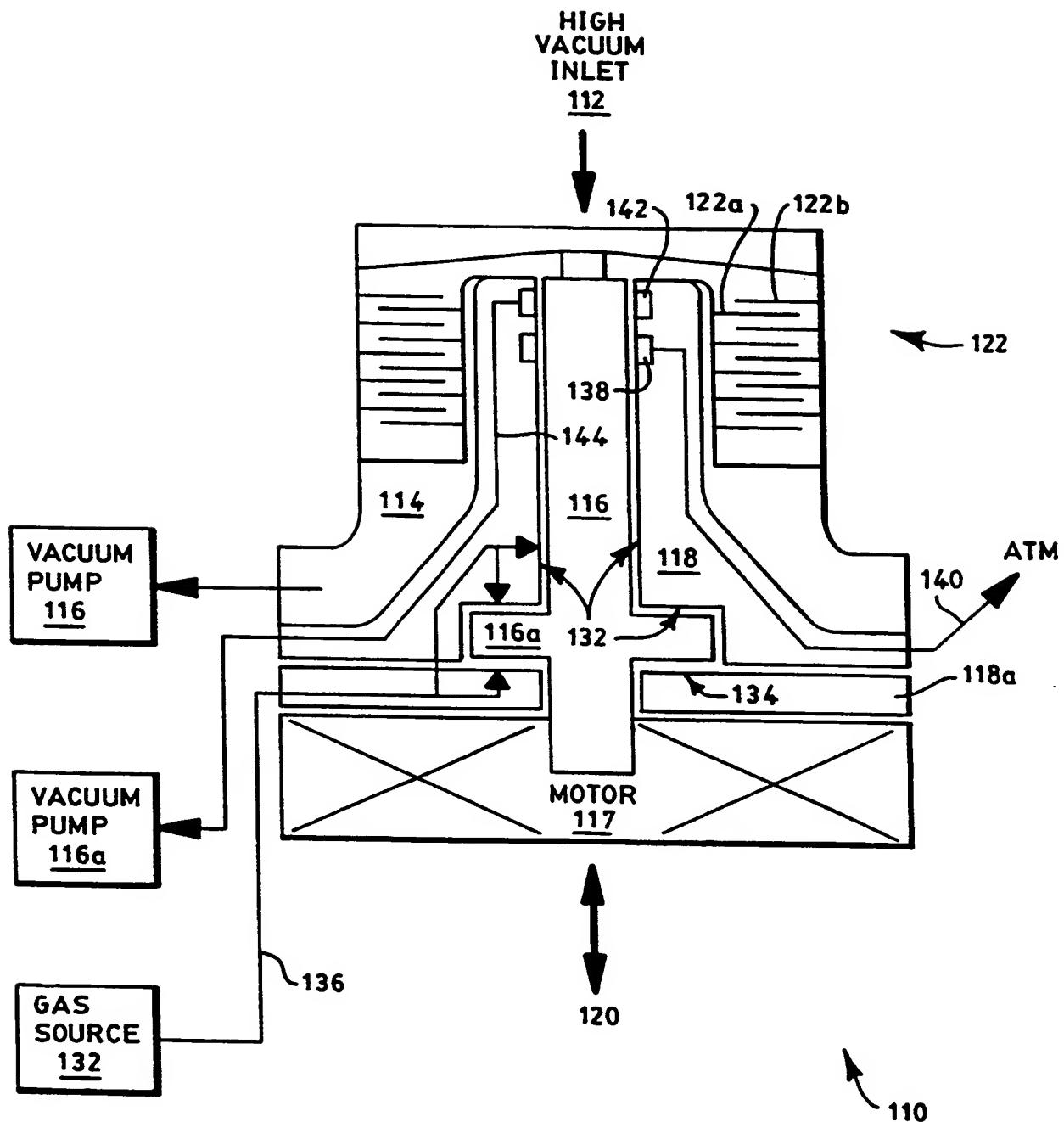
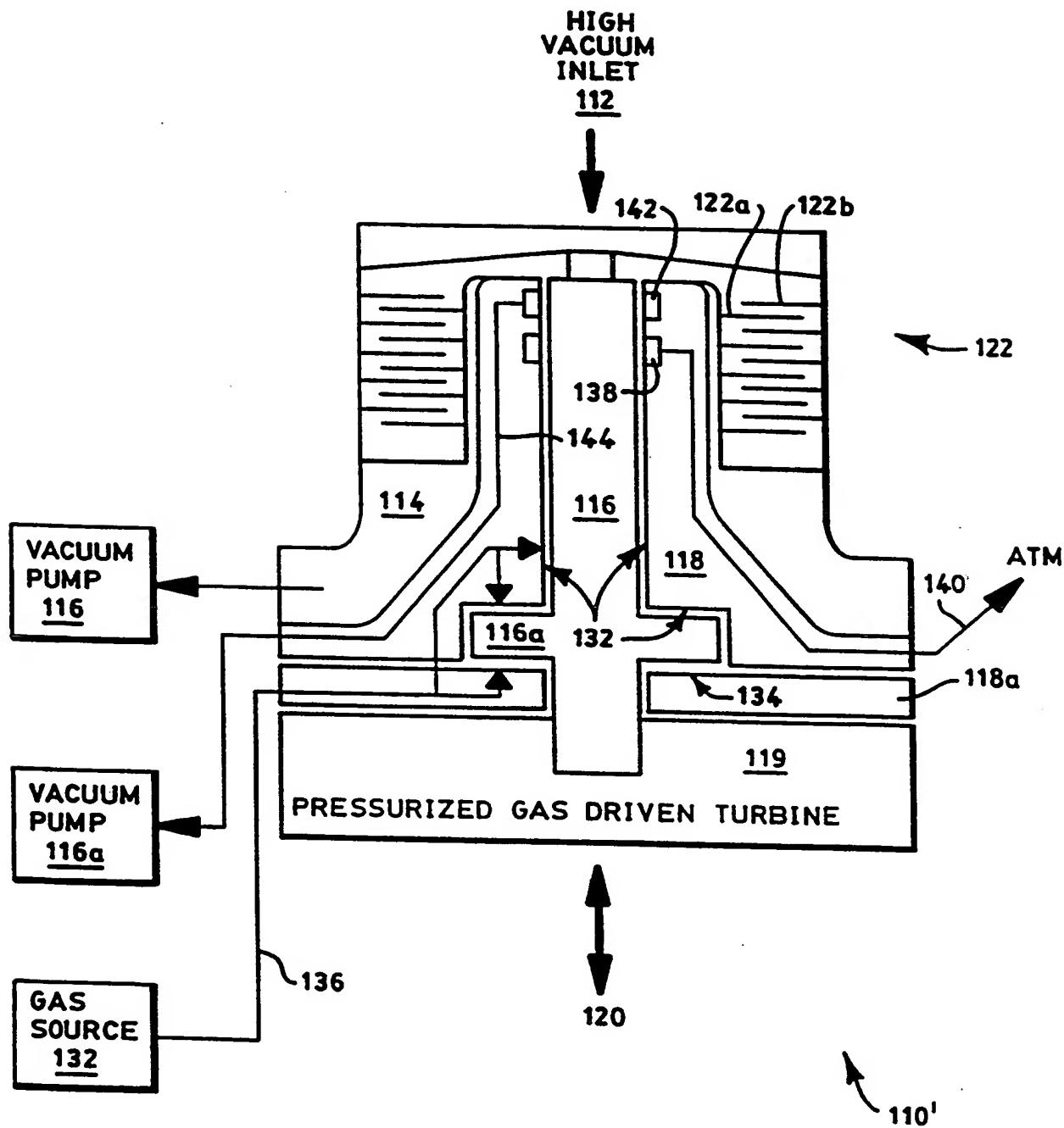


FIG. 5

6/13

**FIG. 5A**

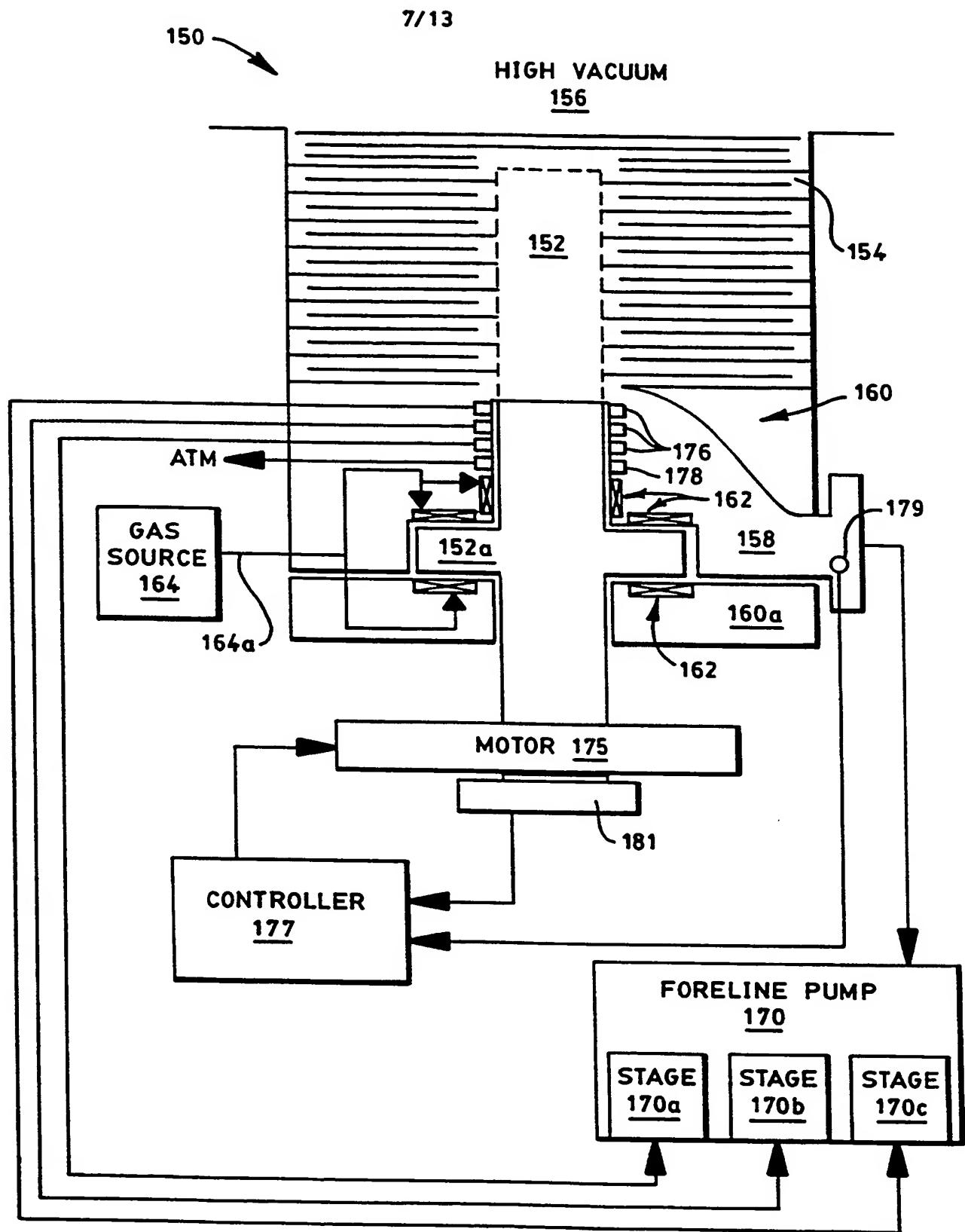
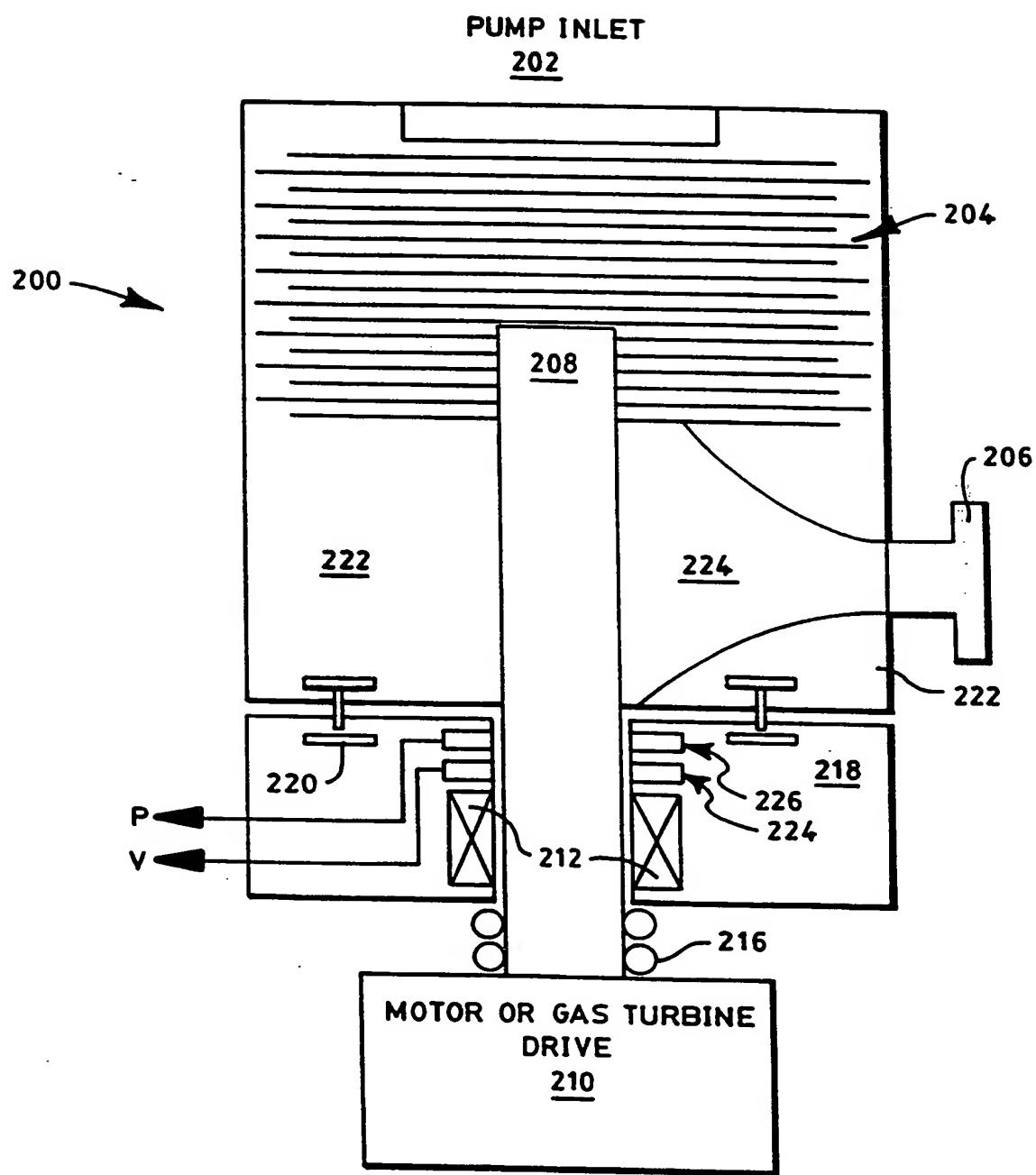
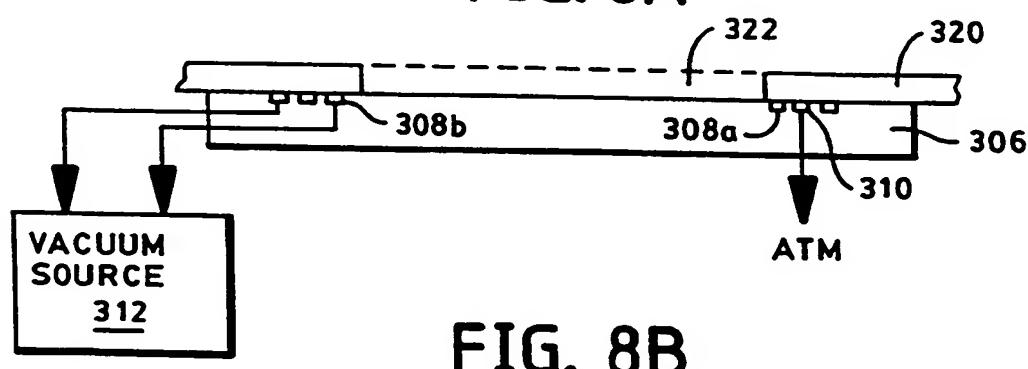
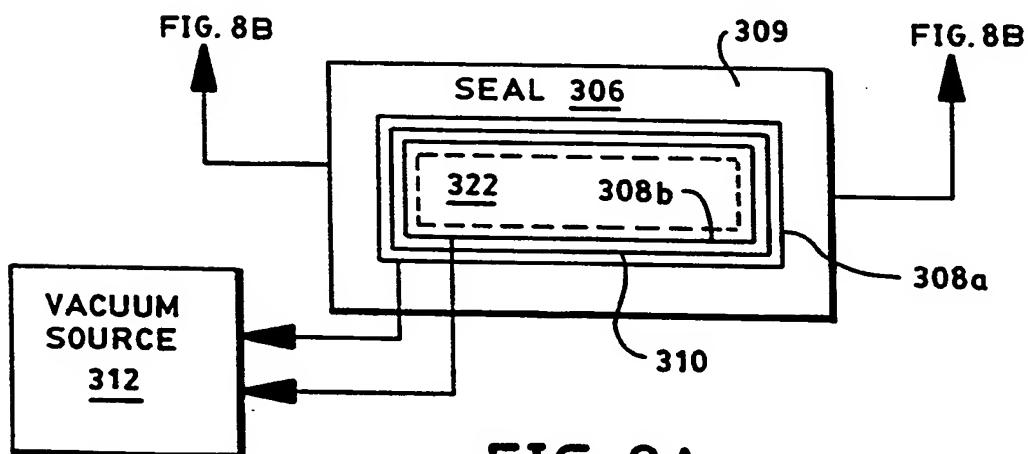
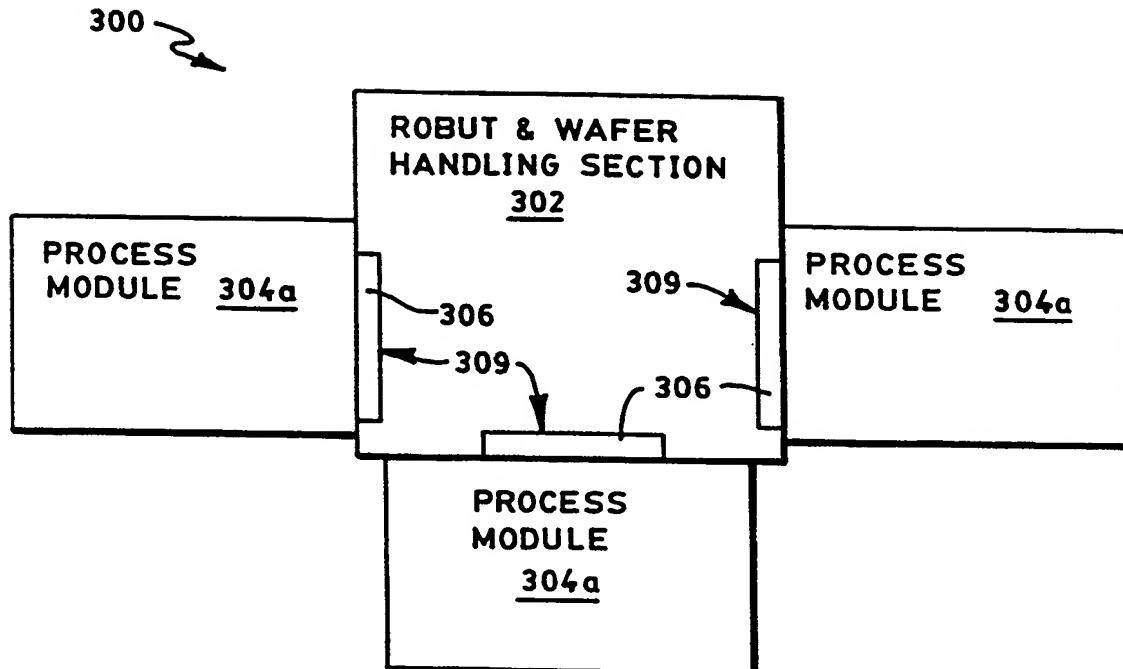


FIG. 6

8/13

**FIG. 7**

9 / 13



10 / 13

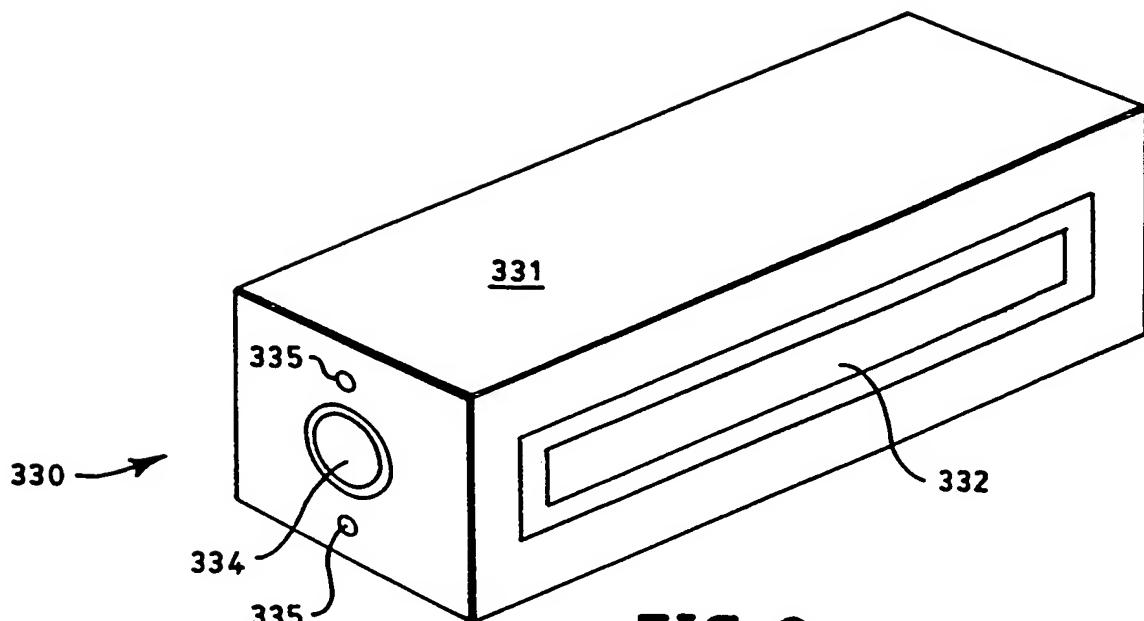


FIG. 9

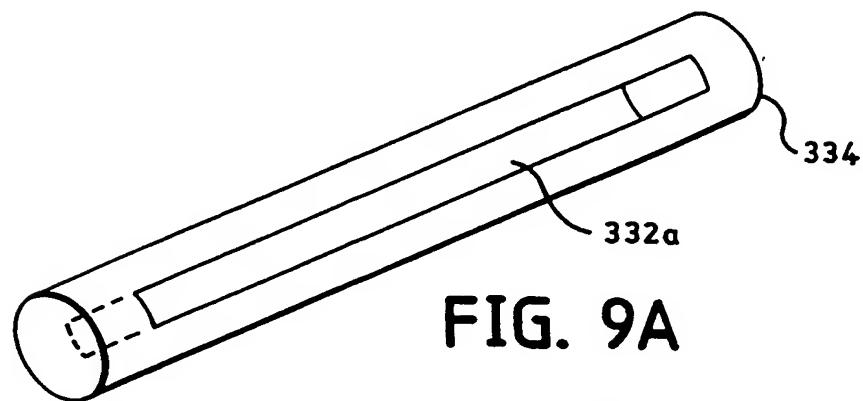


FIG. 9A

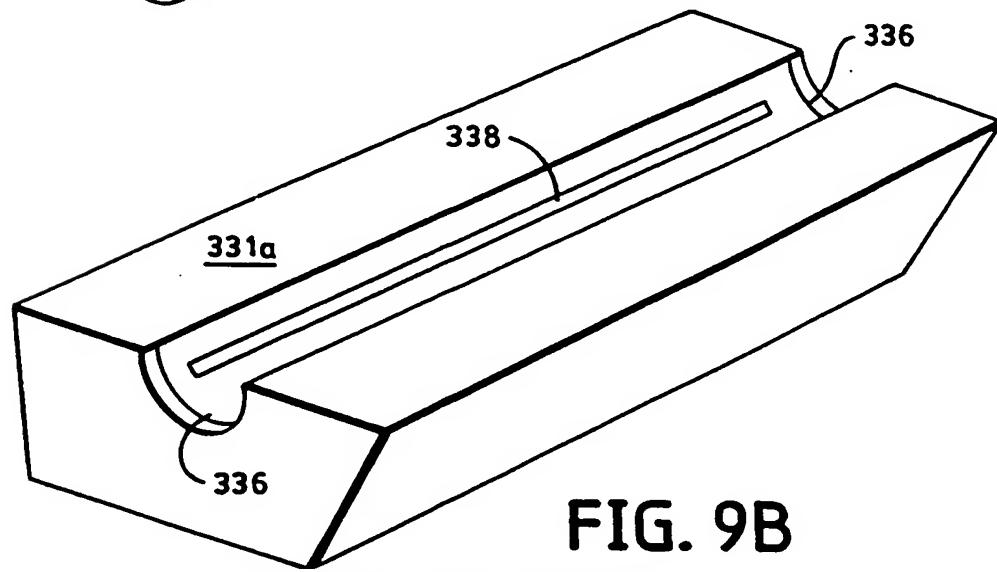


FIG. 9B

SUBSTITUTE SHEET (RULE 26)

11 / 13

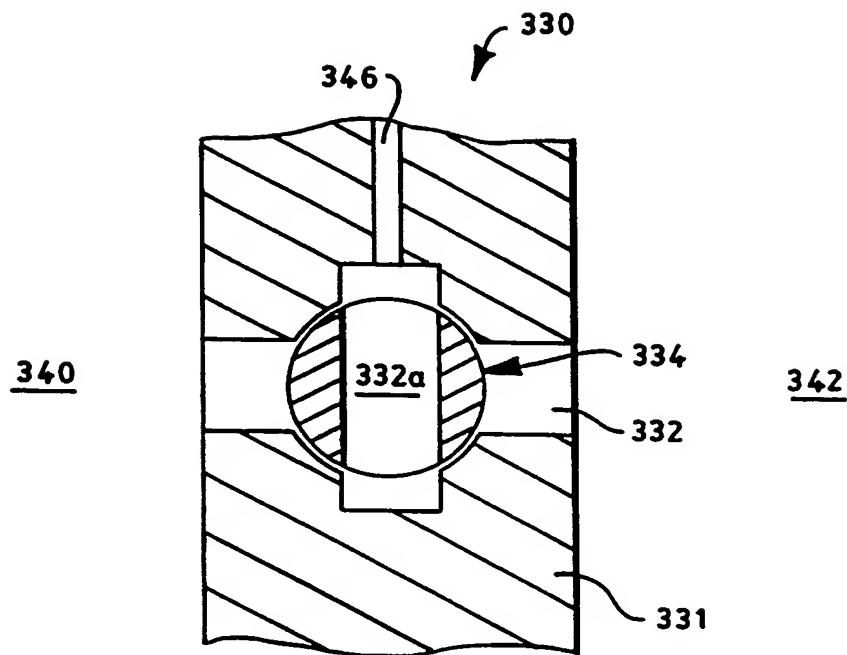


FIG. 9C

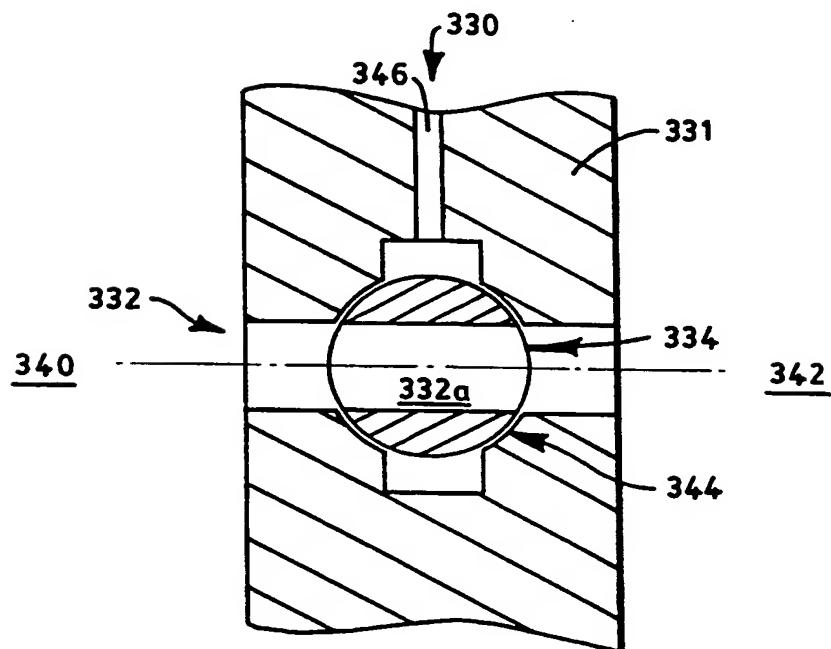


FIG. 9D

SUBSTITUTE SHEET (RULE 26)

12/13

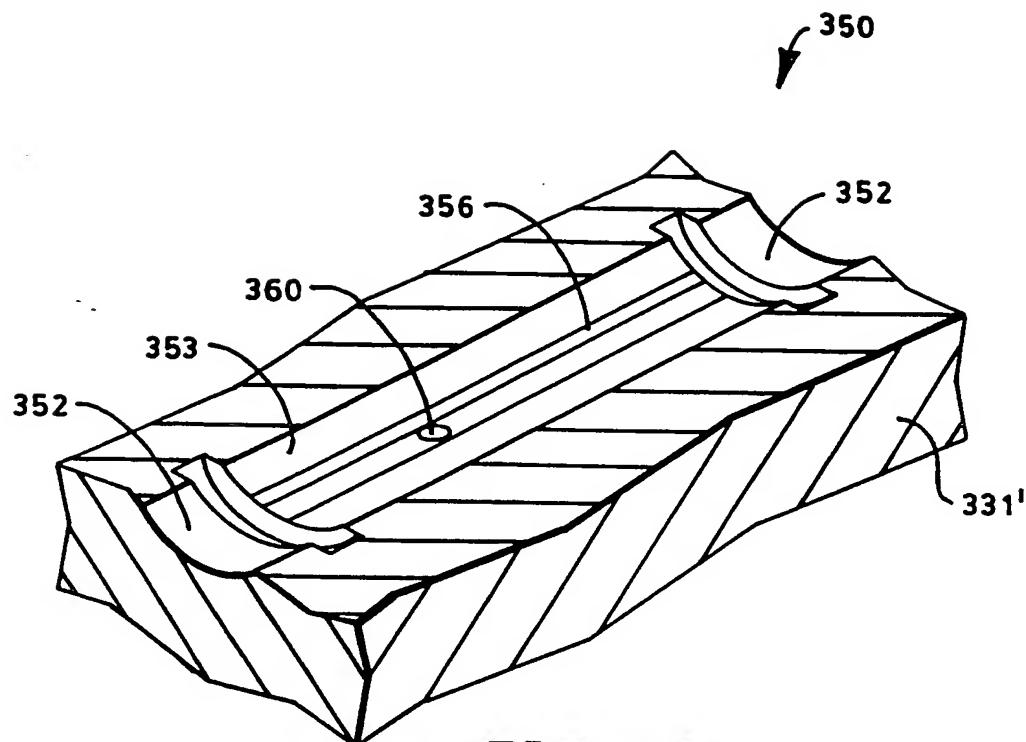


FIG. 9E

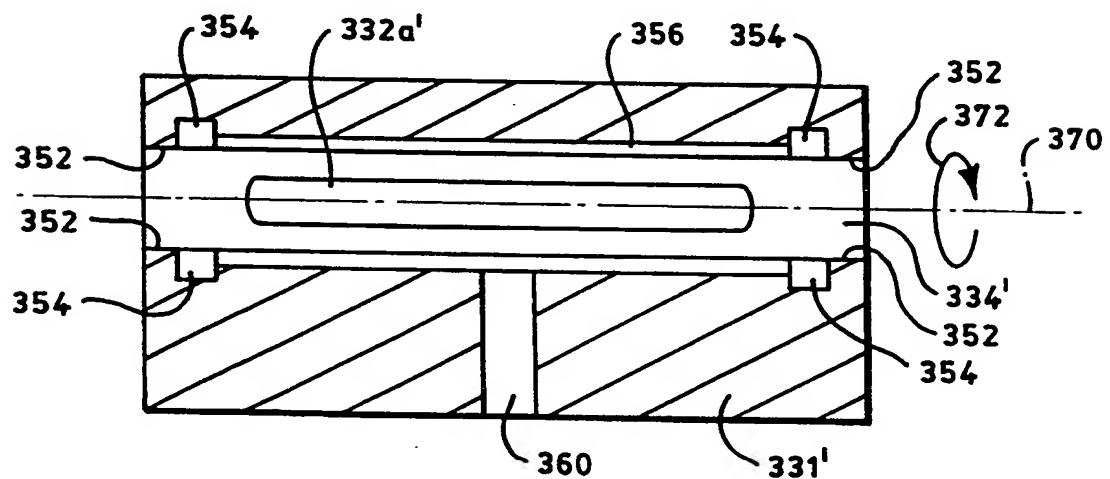


FIG. 9F

SUBSTITUTE SHEET (RULE 26)

13 / 13

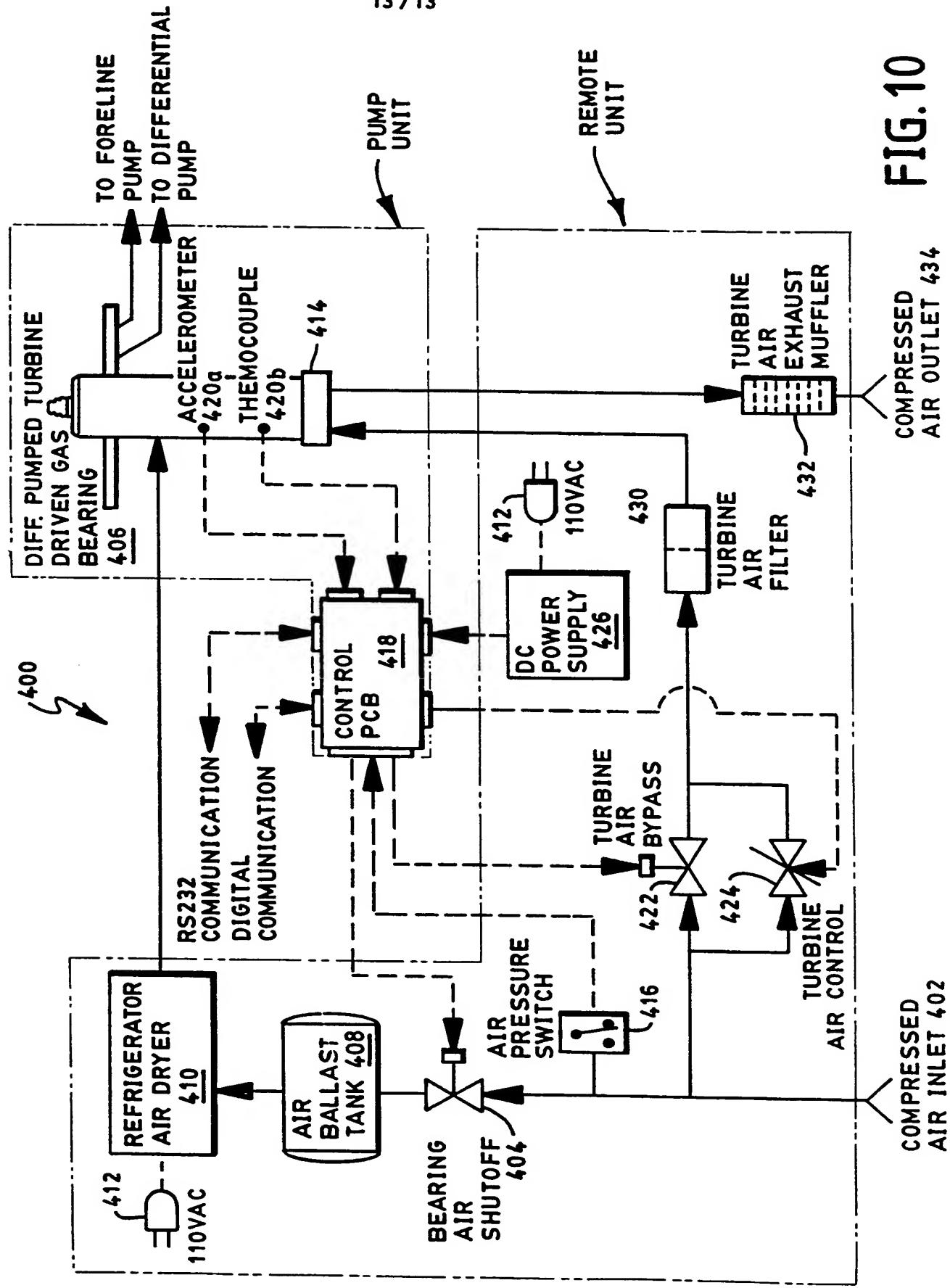


FIG. 10

**COMPRESSED
AIR OUTLET 434**

COMPRESSED
AIR INLET 402

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/21417

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B23Q 1/25; B65G 65/00; F04B 35/04; F16C 33/10, 74
US CL :269/71; 384/16, 114, 131; 414/217; 417/423.4

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 269/55, 58, 71; 384/12, 15, 16, 114, 131, 132; 414/217; 417/423 .4, 423.12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,832,084 A (MAURICE) 27 August 1974, Figs. 1 and 2.	19-25, 28, 29
Y	US 4,726,689 A (POLLOCK) 23 February 1988, Fig. 1.	19-25, 28, 29
---		-----
A		1
A	US 5,224,809 A (MAYDAN et al) 06 July 1993, entire document.	30-36
A	US 5,028,219 A (SCHUETZ et al) 02 July 1991, Fig. 1.	19
A	JP 4-31692 A (IGUCHI) 03 February 1992, Abstract.	19

Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance		
"E" earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
31 DECEMBER 1998	02 FEB 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer BRUCE ANDERSON
Facsimile No. (703) 305-3230	Telephone No. (703) 308-4851

THIS PAGE BLANK (USPTO)